BRITISH RAILWAYS

Mechanical & Electrical Engineering Department

Performance and Efficiency Tests with Exhaust Steam Injector

BRITISH RAILWAYS STANDARD - CLASS 7 2 CYL. 4-6-2 MIXED TRAFFIC LOCOMOTIVE

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APRIL, 1953.

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INTRODUCTION

This class of locomotive was first placed in service in the early part of 1951 and was the first of the Standard Designs to emerge from British Railways.

The purpose of this class was to provide a locomotive with a wide range of route availability and an easy accessability of component parts, which would ultimately take over duties such as are at present carried out by the former L.M. & S. Royal Scot class, the former L. & N. E. V2 class and the former G.W.R. Castle class.

This report is concerned with the performance of the design as it emerged and also forms a basis for the allocation of the class of locomotives to the duties for which it is best suited and to enable those duties to be performed within the most economical range of the locomotive in so far as the Operating Department's requirements are satisfied.

The presentation of the data in this report is divided into two main parts.

The first defines the relationship between coal as fired, water as drawn from the tender, tractive effort and horsepower both as available at the drawbar, data directly applicable to the immediate commercial purpose of examining train loadings and schedules to obtain reduction in fuel consumption by working the locomotives where possible nearest their point of maximum operating efficiency.

The second part concerns itself mainly with thermal efficiency, giving data on a basis of indicated power, covering boiler and cylinder efficiencies, factors of more importance in locomotive design.

The tests were carried out under the direction of Mr. R. A. Riddles, Member(Mechanical and Electrical Engineering) Railway Executive, the work being controlled by the Locomotive Testing Committee consisting of:-

Mr. E.S. Cox (Chair)	-	Executive Officer (Design) R.E.
Dr. H.I. Andrews	-	Electrical Engineering, New Works and Development Section, R.E.
Mr. D.R. Carling	-	Superintending Engineer, Locomotive Testing Station, Rugby
Mr. C.S. Cocks	-	L.M.R. Derby.
MR. S.O. Ell	-	W.R. Swindon.
Mr. R.F. Harvey	-	Chief Officer (Motive Power) R.E.
Mr. T.M. Herbert	-	Director of Research, R.E.
Mr. R.G. Jarvis	-	S.R. Brighton.
Mr. B. Spencer	-	E. & N.E.R. Doncaster.

NATURE OF THE TESTS.

The boiler and cylinder performances were established in the first instance by tests on the stationary testing plant.

These tests were followed by tests on the road by means of the Controlled Road Testing System. On these the boiler efficiencies which had been established on the stationary plant were reproduced and the coal and steam rates also established on the stationary plant were related to the horsepower at the drawbar.

The tests took place at intervals between April, 1951 and February, 1953.

METHOD OF TESTS.

The Plant Tests were carried out at the Locomotive Testing Station, Rugby, and the Controlled Road Tests were carried out between Carlisle and Skipton on the London Midland Region, using the L.M. No. 1 Dynamometer Car.

Tests were carried out using the live steam injector only, the exhaust steam injector only, and both injectors, but in this report only working with the exhaust steam injector is represented, up to the limit of capacity of this fitting, and at higher rates of steaming with both live and exhaust steam injectors used together.

STATIONARY PLANT TESTS.

These were conducted at constant rates of evaporation and combustion and at constant speed.

The coal and water rates were established by the Summation of Increments Method, the constancy of the steaming rate during each test being checked by means of the Swindon steam flow meter.

The range of tests carried out covered speeds from 20 m.p.h. to 75 m.p.h., cut-offs from 15% to 50% and feed water rates from under 10,000 to over 30,000 lb/hr. The majority of the work was performed with full regulator opening.

Indicating was carried out, on the test plant only, using a modified "Farnboro'" type of indicator, as described on pages 4 and 5.

CONTROLLED ROAD TESTS.

These tests were carried out at constant rates of steaming using the Swindon Type Steam Flow Indicator to ensure the necessary constancy and, in general, the same methods of control were exercised over the combustion as with the Stationary Plant tests.

The boiler performance established on the plant was reproduced and the coal and water rates related to the work at the drawbar without difficulty. The ranges of speed and cut-off covered were slightly wider than those covered on the Stationary Plant and Figs. 4 and 5 show parts of the running of two of these tests in diagrammatic form.

At the higher rates of steaming to be attempted it was evident that excessive speeds would be attained even with the maximum weight of train that could be permitted over this route so, for the tests at such rates, use was made of one or two of the Mobile Testing Units to provide an additional resistance above the natural resistance of the train. The Units were not used to hold the speed at any precise predetermined values but simply to keep the speed from rising too high.

TEST ARRANGEMENTS.

The tests both on the Stationary Plant and on the road not only covered the normal working range of the locomotive but indeed went well above any rate of working at present required in practice.

Tests on the Stationary Plant were of varying duration according to the rate of working, ranging generally from 90 mins. to 140 mins. dropping to only 70 mins. for the maximum sustained rate on the plant. The periods are the test periods proper during which unrestricted steaming in stabilised conditions was sustained, after a considerable period of "warming up" at this same rate of steaming.

On the road, due to the limitations of the route, the duration of the test periods was shorter, generally from 60 to 75 minutes for rates of working similar to those actually attained on the test plant and from 50 to 55 minutes for higher rates, but only for 45 minutes for the maximum rate attained owing to human and supply limitations.

When testing a locomotive of this size at a high rate of steaming consideration must be given to the human element: Even for a test run of relatively limited duration the work of firing can become too much for one man to carry out without undue fatigue and for this reason two firemen were used for tests at the higher rates of working. These rates of working are greater than anything normally required for train working in Great Britain, even for periods of quite limited duration.

THE LOCOMOTIVE.

The locomotive first selected for the tests was No. 70005, and further check tests were carried out with No. 70025, the first of the second series of these engines to be turned out from Crewe Works. Both engines were prepared for test during building and they had run in traffic 560 miles and 1040 miles respectively before the first tests to which they were subjected. In all No. 70005

ran 6,890 miles at Rugby and about 5,000 miles on the Road Tests. No. 70025 ran 6,350 miles on Rugby plant only.

Some rapid wear occurred at first on the piston and valve rings of No. 70005, and opportunity was taken whilst the engine was at Rugby to investigate the working of the lubrication system which has resulted in modifications. Although improved, the lubrication still leaves something to be desired under the sustained high output conditions on the plant as distinct from normal service on the road, and investigation is continuing. Variations in steam consumption arising from these ring defects are not thought to have exceeded about 2% on engines otherwise in new condition.

The valves are actuated by Walschaerts motion and the designed valve events are shown in table No. 3.

The ashpan has a damper at the front only and the grate is of the rocking type fitted with "Hulson" firebars: Self cleaning plates are fitted in the smokebox.

EXHAUST STEAM INJECTOR.

Tests with the exhaust steam injector and the live steam injector showed that the water consumption was reduced by 6% when using the exhaust steam injector and the corresponding coal economy, depending on the rate of steaming, ranged from about 6½% at the lowest rates of working to about 9% at the capacity working of the exhaust steam injector.

The exhaust steam injector, Davies & Metcalfe Class "K" 11 m.m., has a specified maximum delivery of 2530 gallons per hour. 2200 gallons of feed water per hour was the highest figure actually sustained on the Stationary Plant.

The live steam injector, a Western Region 11X, will deliver feed water up to the limit of the boiler's steaming capacity.

"FARNBORO'" INDICATOR.

Indicating was carried out with a modified "Farnboro'" indicator and a number of representative diagrams are reproduced herewith.

The indicator produces diagrams on a basis of angle of rotation of the driving axle instead of the stroke basis hitherto most familiar, and also builds up the diagram over a large number of revolutions instead of one or two.

The diagram is composed of a number of dots produced by perforating a special paper with an electric spark, the position of the spark being determined on one axis by the angular position of the axle and on the other by the pressure of steam in the cylinder. This is done by picking up electrically the moment when the steam pressure balances a gas pressure that can be varied at will and which operates the spark pointer of the indicator.

The modifications to the original indicator, to make it suitable for use on a steam locomotive, have been concerned with the pressure sensitive elements to make these suitable for use in contact with either wet or superheated steam and with the electrical system to enable all four cylinder ends to be indicated simultaneously and to speed up the process appreciably, this now requiring about half a minute.

It is, of course, most important that the rate of steaming, the speed and the cut-off should be kept constant throughout the taking of any one set of diagrams. On the test plant the cut-off and regulator openings are kept fixed and the boiler pressure and speed held within very close limits, thus also keeping the steam flow within close limits, checked by means of the steam flow indicator.

A number of careful and methodical comparative tests have been made with the latest piston indicators of the Dobbie McInnes type, these latter being fitted as close as possible to the cylinders. The tests covered the normal working range of the locomotive for both speed and steaming rates, and showed only small differences between the two types of indicator, mostly less than variations between diagrams taken with either indicator. Taken broadly over the whole range of the tests the results are within 1% of one another.

The representative diagrams shown, about $\frac{3}{4}$ full size, cover both normal and exceptionally high rates of working. Once the different appearance of the diagrams has become familiar they are found to give a very clear picture of the events in the cylinders. They can be converted into stroke base diagrams by either graphical or mechanical means and in the latter case the area can be obtained at the same time, but in the former it must either be computed or measured separately. The short vertical rows of dots are due to phasing contacts to assist conversion of the diagrams.

COAL.

The tests covered by this bulletin were carried out using two coals:-

South Kirkby, a Grade 1A Hard South Yorkshire,

Blidworth, a Grade 2B Hard East Midlands.

The South Kirkby coal was supplied in very large pieces which were broken down to "Cobbles" for firing. The consequent slack was screened out for the sake of uniformity and only over 1" size was fired.

The Blidworth coal was supplied as "Small Cobbles" and as such is very suitable for firing.

In each coal the various samples showed little variation in analysis and calorific value; representative values and analyses are given in the table.

At the time these tests took place the South Kirkby coal cost £3.3.10d. and the Blidworth £2.18.11d. per ton, on the tender at Carlisle Motive Power Depot, not including the cost of haulage.

TABLE No. 1.

	SOUTH KIRKBY		BLIDWORTH	
	AS RECEIVED	DRY	AS RECEIVED	DRY
CALORIFIC VALUE				
Calories per gram	7667	7920	7000	7616
British Thermal Units per lb.	13800	14256	12600	13710
Pounds of water at 212° F converted into steam at the same temperature by 1 lb. of coal.	14.23	14.67	12.99	14.13
PROXIMATE ANALYSIS				
Moisture %	3.24	-	8.14	-
Volatile Matter, less moisture %	34.71	35.87	32.62	35.50
Fixed Carbon %	57.38	59.30	53.84	58.62
Ash %	4.67	4.83	5.40	5.88
Total Sulphur%	1.15	1.19	0.76	0.83
Coke: Character	Hard, Unswollen		Dull grey, hard, unswollen	
Ratio of volume to that of coal	1 : 1		1 : 1	
Ash	Brown		Light Brown.	

OBSERVATIONS

The cylinder efficiency is consistent with that of other locomotives of modern design having similar clearance volumes, and working over the same range of pressure and temperature.

Sharp clear indicator cards were obtained for any steam rate actually attained on the test plant. At 30,000 lb/hr. 2110 I.H.P. was developed at 37½% cut-off at 53½ m.p.h. at which point steam consumption was 14.2 lbs. per I.H.P. hour.

The lowest specific steam consumption was 13.28 lbs. per I.H.P. hour at 20% cut-off at 70 m.p.h. when 20,000 lbs of steam per hour were being used to develop 1506 I.H.P. At this point cylinder thermal efficiency was 14% which is 68% of the maximum efficiency possible under the Rankine cycle.

Interest centres in this locomotive on the large boiler provided. Certain features of the performance are shown up clearly by these test results, but there are others, advantageous to the Operating Department, and referred to later, which do not emerge from the controlled constant conditions of test procedure.

The maximum boiler capacity is deliberately limited by the draughting arrangement provided, which is such to promote economical combustion at normal rates of working: Nevertheless it is sufficient for a continuously sustained evaporation of 30,200 lb/hr. of feed water and for as much as 36,150 lbs/hr. maintained for three quarters of an hour on the road. These values are beyond the capacity of a single fireman and two men were employed in this range.

The draughting arrangement satisfactorily covers the whole range of working of which one fireman is capable, and it also covers the range of most economical working of the locomotive as a whole.

With the two qualities of coal tested, the front end arrangement permitted an evaporation of 30,000 lbs. of feed water per hour, the amount of coal required for this rate of evaporation being, of course, higher for the lower grade of coal. Boiler efficiency with South Kirkby coal was still 75% when 3000 lbs of coal per hour was being fired, which is about the upper limit for hand firing. A corresponding efficiency for the B.R. Class 5 engine with the same quantity of similar coal fired (Bulletin 6) was 69%, and for any quantity of coal fired above 1000 lbs/hr. there is an appreciable advantage in efficiency for the larger boiler. With Blidworth coal the Class 7 boiler efficiency was lower throughout the range than with South Kirkby. Moreover, with Blidworth coal the Class 7 boiler efficiency is lower than that for the Class 5 at the lower rates of working, although it surpasses it at the higher rates (over 2,330 lbs/hr.). This is a feature observed on other tests with wide firebox engines.

There was some evidence that the distribution of air over the grate would have been improved by provision of an additional damper door at the rear.

These matters have been thrown up by this series of tests as subjects for further investigation.

It will be noted that the exhaust steam injector with 11 m.m. cones could only be worked up to a tender water feed of 22,000 lbs/hr. The admixture of cold boiler feed above this rate represents a debit to boiler and overall efficiencies which must be borne in mind when comparing the results with other types of locomotives.

Two features of the larger boiler, of value to the Operating Department, which are not brought out by the test results are:-

(a) The ability of a larger grate to carry more clinker or ash from poor quality coal before the air supply through the fuel bed becomes sufficiently restricted to affect steaming adversely. This feature will be brought out in the Bulletin for the W.D. 2-8-0 and 2-10-0 locomotives shortly to be published.

(b) The larger reservoir capacity both in heat and steam which provides a reserve for short periods of heavy demand, such as acceleration up a grade after a check and to tide over temporarily adverse firing conditions.

Although the maximum steam supply to the cylinders which was sustained continuously on the test plant for well over an hour was 31,610 lbs/hr., an interesting road test is partially represented in Fig. 4 on which a steam rate to cylinders of 37,560 lbs/hr. was maintained for 45 minutes. This represented the haulage of an 850 ton passenger train over the Carlisle - Leeds route at limited load timings, and at this rate of working a further engine limit began to be reached, namely, that of adhesion under running conditions. When rail conditions are good this limit usually exceeds the corresponding limit on the test plant.

The corresponding rostered Class 7 load over this route is 405 tons, and the difference represents the potential which the engine possesses to meet adverse operating conditions.

TABLE No. 2.

B.R. STANDARD CLASS 7

BOILER LIMITS

SUSTAINED RATES.

	Limit of Exhaust Steam Injector	Estimated Limit for one Fireman.	Maximum Attained on Test Plant	Front End Limit
SOUTH KIRKBY COAL				
C.V. 13800 (B.Th.U/lb)				
Feed Water lb/hr.	22000	23100	30200	
Steam lb/hr.	23410	24510	31610	
Coal lb/hr.	2813	3000	4320	
BLIDWORTH COAL				
C.V. 12600 (B.Th.U/lb)				
Feed Water lb/hr.	22000	19800		30000
Steam lb/hr.	23410	21060		31410
Coal lb/hr.	3411	3000		5066

The figure given for the limit of one fireman must of course be a purely arbitrary one depending as it does to some extent on the particular engine, and also on the time factor.

Care must be taken in applying the above coal rate of 3000 lb/hr. - approximately five shovels per minute - as it must be maintained continuously if the steam rate is to be maintained continuously, and there are, after all, other duties which a fireman is expected to perform when the locomotive is in traffic.

B.R. CLASS 7 ENGINES. DIMENSIONAL

DETAILS AND RATIOS

CYLINDER AND STEAM CHESTS

Piston swept volume	cu.ins.	8796
Cylinder clearance volume as % of piston swept volume		10.3
Steam chest volume as % of piston swept volume		51.8

PISTON VALVE

Nominal diameter	ins.	11
Steam lap	ins.	1.11/16
Lead	ins.	1/4
Exhaust clearance		NIL
Maximum cut-off Forward gear	%	77.5
Maximum cut-off Back gear	%	74.7
For designed valve setting see separate table.		

BOILER

Barrel diameter outside min.		5' 9"
max.		6' 5½"
Small tubes number		136
outside dia.	ins.	2.1/8"
Thickness		11 S.W.G.
Large tubes number		40
outside dia.	ins.	5.1/2"
thickness		7 S.W.G.
Superheater elements (double return loop)		
outside dia.	ins.	1.3/8"
thickness		10 S.W.G.
Length between tube plates		17' 0"
Heating surfaces) See Engine diagram		
Grate area)		
Water surface at half glass	sq.ft.	121.8
Volume of steam above water at half glass	cu.ft.	148.4
Total piston swept volume as % of steam volume		6.86
Firebox volume / grate area		6.53
Firebox volume / Firebox heating surface		1.3
A/S Large tubes		1/420
A/S Small tubes		1/435

EAM CIRCUIT

gulator area through pilot valve	sq.ins.	1.64
" " " all valves open	sq.ins.	48.8
n steam pipe through boiler dia.	ins.	7
cross sectional area	sq.ins.	38.48
perheater elements area through		
spherical ends	sq.ins.	34.96
through tubes	sq.ins.	39.3
am pipes to cylinders bore	ins.	6
cross sectional area	sq.ins.	28.27
am chest, cross sectional area		
through liner	sq.ins.	91.2
ts width	ins.	2.1/4
cross sectional area	sq.ins.	56.6
sage steam chest to cylinder min.		
cross sectional area	sq.ins.	41.9
aust passage		
max. cross sectional area adjacent to steam chest	sq.ins.	62.5
at point of convergence of four passages below blast pipe	sq.ins.	107.5
st pipe cap, see Draughting Arrangements		

CIRCUIT

a through ashpan dampers front	sq.ft.	3.47
space through grate as % grate area		37.0
e area through tubes large	sq.ft.	4.13
small	sq.ft.	2.66
total	sq.ft.	6.79
a through large tubes as % of total free area		60.9
al free tube area as % of grate area		16.2
mney choke, see Draughting Arrangements		

UGHTING ARRANGEMENTS

st pipe orifice dia.	ins.	5.3/8
area	sq.ins.	22.69
mney dia. at choke		1' 3.5/8"
area at choke	sq.ft.	1.29
dia. at top		1' 5.31/64"
st pipe orifice below smokebox centre line		1' 4.1/2"
mney choke above blast pipe orifice		2'10.3/4"
ght of chimney choke to top		2' 2.1/4"
mney sides taper		1 in 14

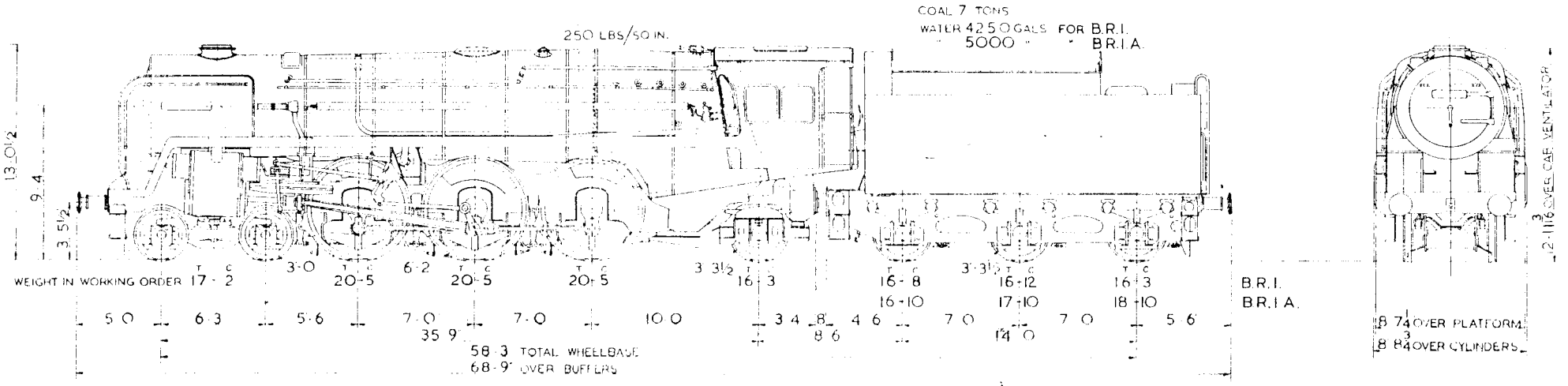
mney choke dia.

st pipe orifice dia.	2.91

ght of choke above orifice

of choke	2.25

SL/7A/1



BOILER BARREL DIAMETER (OUTSIDE)	5'-9" INCREASING TO 6'-5½"
FIREBOX (OUTSIDE)	7'-0" LONG x 7'-9" TO 7'-4" WIDE
TUBES	40 LARGE 5½" O.D. x 7 S.W.G.
	136 SMALL 2⅛" O.D. x 11 S.W.G.
SUPERHEATER ELEMENTS	1⅜" O.D. x 10 S.W.G.
LENGTH BETWEEN TUBEPLATES	17'-0"
HEATING SURFACES: TUBES	2264 SQ. FT.
FIREBOX	210 SQ. FT.
TOTAL EVAPORATIVE	2474 SQ. FT.
SUPERHEATER	718 SQ. FT.
FREE FLUE AREA	6·8 SQ. FT.
GRATE AREA	42 SQ. FT.

CYLINDERS (TWO)	20" x 28"
TRACTIVE EFFORT	32,150 LBS
ADHESION FACTOR	4·23
BRAKE % ENGINE & TENDER	53·4 B.R.I. TENDER. 52·5 B.R.I.A. TENDER.
MINIMUM RADIUS CURVE (WITH SPECIFIED GAUGE WIDENING)	4½ CHAINS.
BOILER TYPE	B.R.1.
TENDER TYPE	B.R.1 OR B.R.1.A.

WEIGHTS	WITH B.R.I. TENDER. FULL T-C	WITH B.R.I. TENDER. EMPTY T C	WITH B.R.I.A. TENDER FULL T-C	WITH B.R.I.A. TENDER EMPTY T-C
ENGINE	94-0	85-3	94-0	85-3
TENDER	49-3	23-3	52-10	23-3
TOTAL	143-3	108 6	146-10	108 6

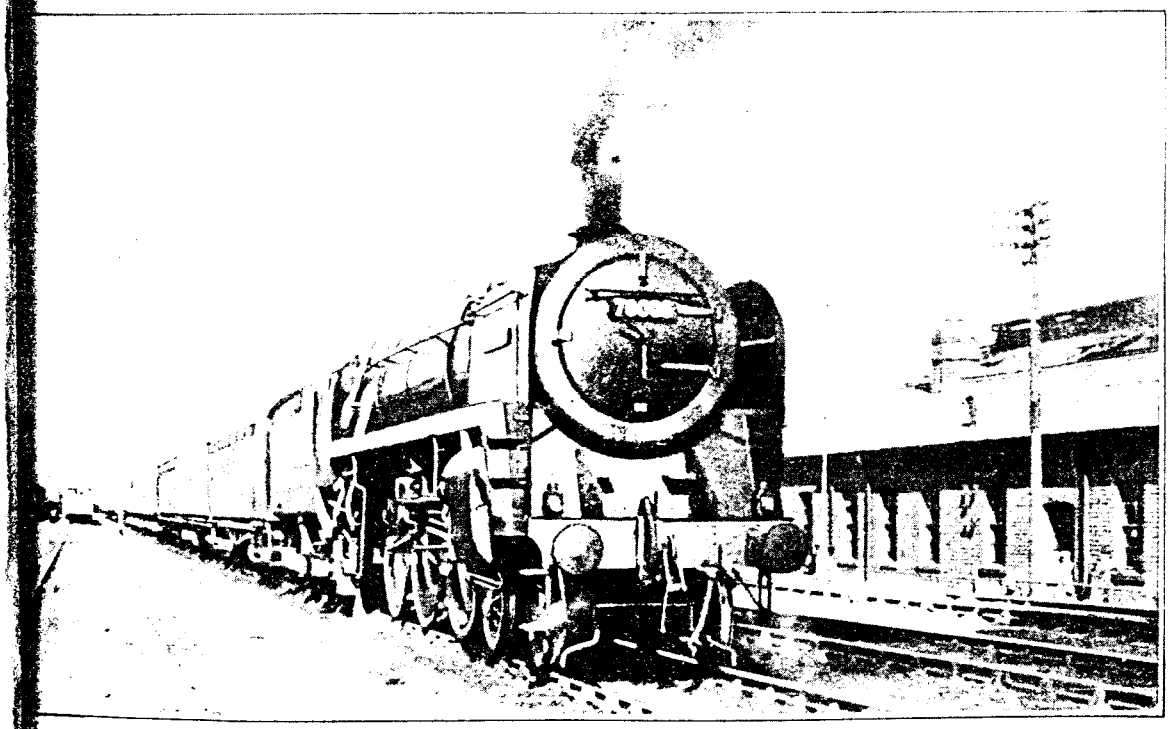
SCALE
0 2 4 6 8 10 FEET

STANDARD CLASS 7. 4-6-2 ENGINE.

FIG.1.

Photo. Topical Press

No.70,005 Running on the Rugby Test Plant.



No.70,005 and 11 Vehicles, Weight 338 Tons, including L.M. Region No.1 Dynamometer Car, about to leave Skipton 4th. June, 1951.

FORWARD GEAR.

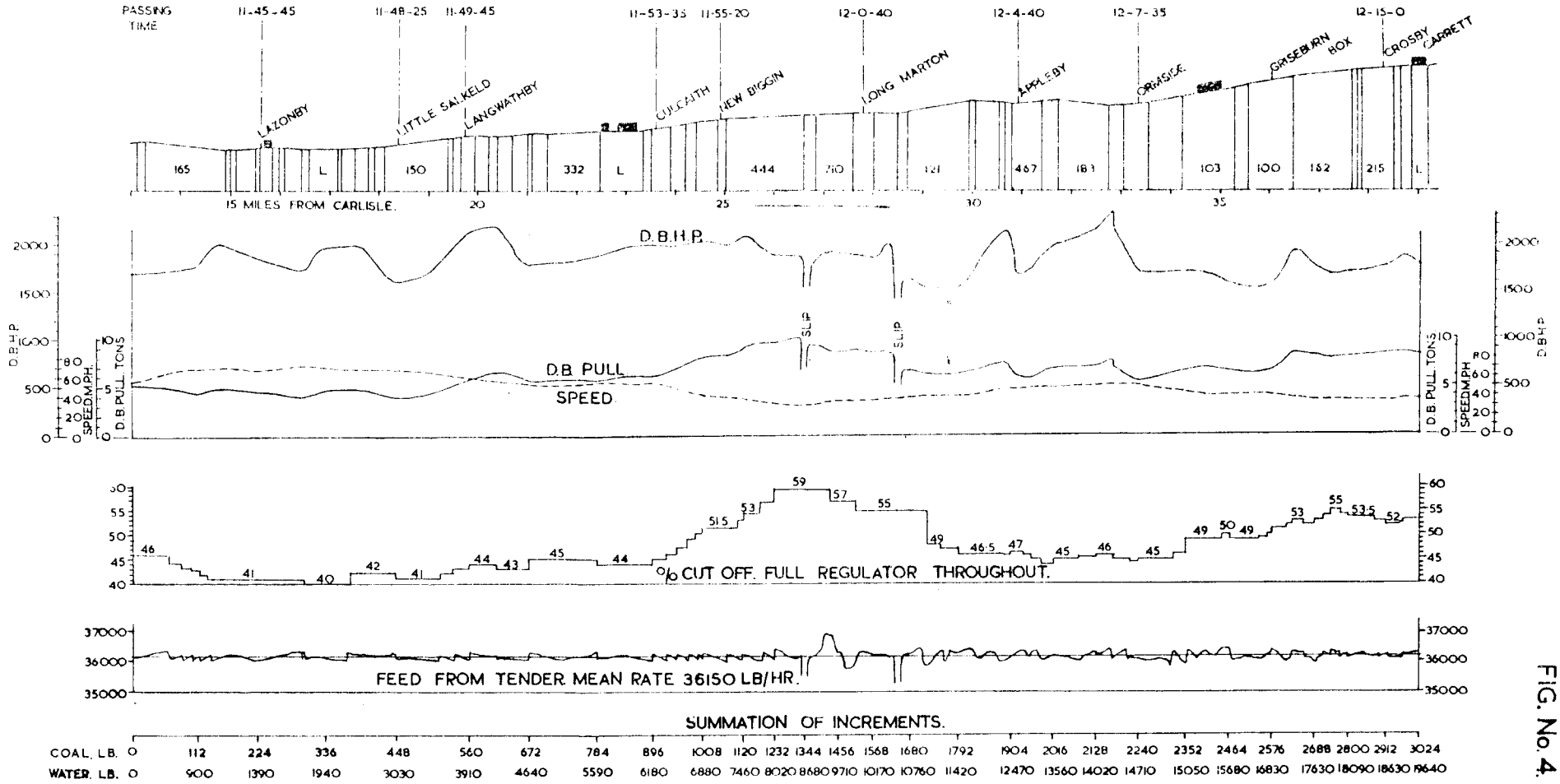
NOMINAL CUT OFF		TRAVEL IN	LEAD IN INCHES			PORT OPENING IN INCHES			CUT OFF %			EXPANSION %			RELEASE %			ANGLE OF RELEASE DEGREES			COMPRESSION %			EXHAUST TRAVEL IN INCHES		
NOTCH	ANGLE	INCHES	F	B	D	F	B	D	F	B	D	F	B	D	F	B	D	F	B	D	F	B	D	F	B	D
78	19	$7\frac{3}{4}-\frac{1}{64}$	$\frac{1}{4}$	$\frac{1}{4}$	0	$2\frac{1}{32}$	$2\frac{5}{16}+\frac{1}{64}$	$\frac{5}{16}-\frac{1}{64}$	79·2	75·9	3·3	14·6	16·3	1·7	93·8	92·2	1·6	$149\frac{1}{2}$	149	$\frac{1}{2}$	92·2	93·8	1·6	$4\frac{1}{64}$	$3\frac{23}{32}$	$\frac{5}{16}-\frac{1}{64}$
75	$17\frac{1}{4}$	$7\frac{1}{4}-\frac{1}{64}$	"	"	"	$1\frac{13}{16}$	$2\frac{1}{16}-\frac{1}{64}$	$\frac{1}{4}-\frac{1}{64}$	76·5	72·8	3·7	16·4	18·2	1·8	92·9	91·0	1·9	147	$146\frac{1}{2}$	$\frac{1}{2}$	91·0	92·9	1·9	$3\frac{3}{4}-\frac{1}{64}$	$3\frac{1}{2}$	$\frac{1}{4}-\frac{1}{64}$
70	15	$6\frac{5}{8}$	"	"	"	$1\frac{17}{32}$	$1\frac{23}{32}$	$\frac{3}{16}$	72·0	68·0	4·0	19·3	21·1	1·8	91·3	89·1	2·2	$143\frac{1}{2}$	143	$\frac{1}{2}$	89·1	91·3	2·2	$3\frac{13}{32}$	$3\frac{7}{32}$	$\frac{3}{16}$
60	$11\frac{1}{2}$	$5\frac{11}{16}-\frac{1}{64}$	"	"	"	$\frac{1}{16}+\frac{1}{64}$	$1\frac{7}{32}$	$\frac{1}{8}+\frac{1}{64}$	62·1	58·3	3·8	25·6	26·7	1·1	87·7	85·0	2·7	$136\frac{1}{2}$	136	$\frac{1}{2}$	85·0	87·7	2·7	$2\frac{29}{32}$	$2\frac{3}{4}+\frac{1}{64}$	$\frac{1}{8}+\frac{1}{64}$
50	$8\frac{7}{8}$	$5\frac{1}{32}$	"	"	"	$\frac{25}{32}$	$\frac{7}{8}$	$\frac{3}{32}$	51·2	48·9	2·3	32·4	31·7	·7	83·6	80·6	3·0	$129\frac{1}{2}$	$129\frac{1}{2}$	0	80·6	83·6	3·0	$2\frac{9}{16}$	$2\frac{15}{32}$	$\frac{3}{32}$
40	$6\frac{7}{8}$	$4\frac{9}{16}+\frac{1}{64}$	"	"	"	$\frac{9}{16}$	$\frac{5}{8}+\frac{1}{64}$	$\frac{1}{16}+\frac{1}{64}$	40·2	39·7	·5	39·0	36·5	2·5	79·2	76·2	3·0	123	124	1	76·2	79·2	3·0	$2\frac{5}{16}+\frac{1}{64}$	$2\frac{1}{4}$	$\frac{1}{16}+\frac{1}{64}$
30	$5\frac{1}{8}$	$4\frac{5}{16}-\frac{1}{64}$	"	"	"	$\frac{7}{32}$	$\frac{1}{2}-\frac{1}{64}$	$\frac{1}{16}-\frac{1}{64}$	29·6	30·7	1·1	44·4	40·8	3·6	74·0	71·5	2·5	116	118	2	71·5	74·0	2·5	$2\frac{3}{16}-\frac{1}{64}$	$2\frac{1}{8}$	$\frac{3}{64}$
25	$4\frac{1}{4}$	$4\frac{5}{32}$	"	"	"	$\frac{3}{8}$	$\frac{13}{32}$	$\frac{1}{32}$	24·2	25·8	1·6	46·6	42·9	3·7	70·8	68·7	2·1	$111\frac{1}{2}$	$114\frac{1}{2}$	3	67·8	70·8	3·0	$2\frac{3}{32}$	$2\frac{1}{16}$	$\frac{1}{32}$
20	$3\frac{1}{4}$	$4\frac{1}{16}-\frac{1}{64}$	"	"	"	$\frac{5}{16}+\frac{1}{64}$	$\frac{11}{32}$	$\frac{1}{64}$	19·3	20·8	1·5	47·6	44·7	2·9	66·9	65·5	1·4	$106\frac{1}{2}$	$110\frac{1}{2}$	4	65·5	66·9	1·4	$2\frac{1}{32}$	$2\frac{1}{64}$	$\frac{1}{64}$
15	$2\frac{1}{4}$	$3\frac{15}{16}+\frac{1}{64}$	"	"	"	$\frac{9}{32}$	$\frac{5}{16}-\frac{1}{64}$	$\frac{1}{64}$	14·3	15·7	1·4	47·9	46·1	1·8	62·2	61·8	·4	101	106	5	61·8	62·2	·4	$2-\frac{1}{64}$	$1\frac{31}{32}$	$\frac{1}{64}$
0	0	$3\frac{7}{8}$	"	"	"	$\frac{1}{4}$	$\frac{1}{4}$	0	7·1	7·2	·1	43·9	44·9	1·0	51·0	52·1	1·1	88	95	7	52·1	51·0	1·1	$1\frac{15}{16}$	$1\frac{15}{16}$	0
DIE BLOCK CLEARANCE $1\frac{3}{32}$"						SLIP $\frac{9}{32}$"			LAP $1\frac{11}{16}$"			EXHAUST CLEARANCE NIL			MAXIMUM VALVE TRAVEL $7\frac{3}{4}$"											

VALVE EVENT TABLE.

FIG.3.

DYNAMOMETER CAR TEST No. 1040. 15. FEB. 1952.
SOUTH KIRKBY COAL. 14,000 B.Th.U./LB. AS FIRED.
EXHAUST STEAM INJECTOR, SUPPLEMENTED BY LIVE.

LOAD 430 TONS INCLUDING 2 MOBILE TESTING UNITS.
APPROXIMATE EQUIVALENT LOAD = 850 TONS.
WATER RATE 36,150 LB/HR.
(FEED FROM TENDER.)
COAL RATE 5600 LB/HR.
(INCLUSIVE OF REQUIREMENTS OF AUXILIARIES)



EXAMPLE OF RUN AT CONSTANT EVAPORATION
AT HIGH STEAMING RATE.

FIG. No. 4.

EXAMPLE OF TEST AT CONSTANT EVAPORATION UNDER CONDITIONS GIVING APPROXIMATELY MOST ECONOMICAL COAL CONSUMPTION.

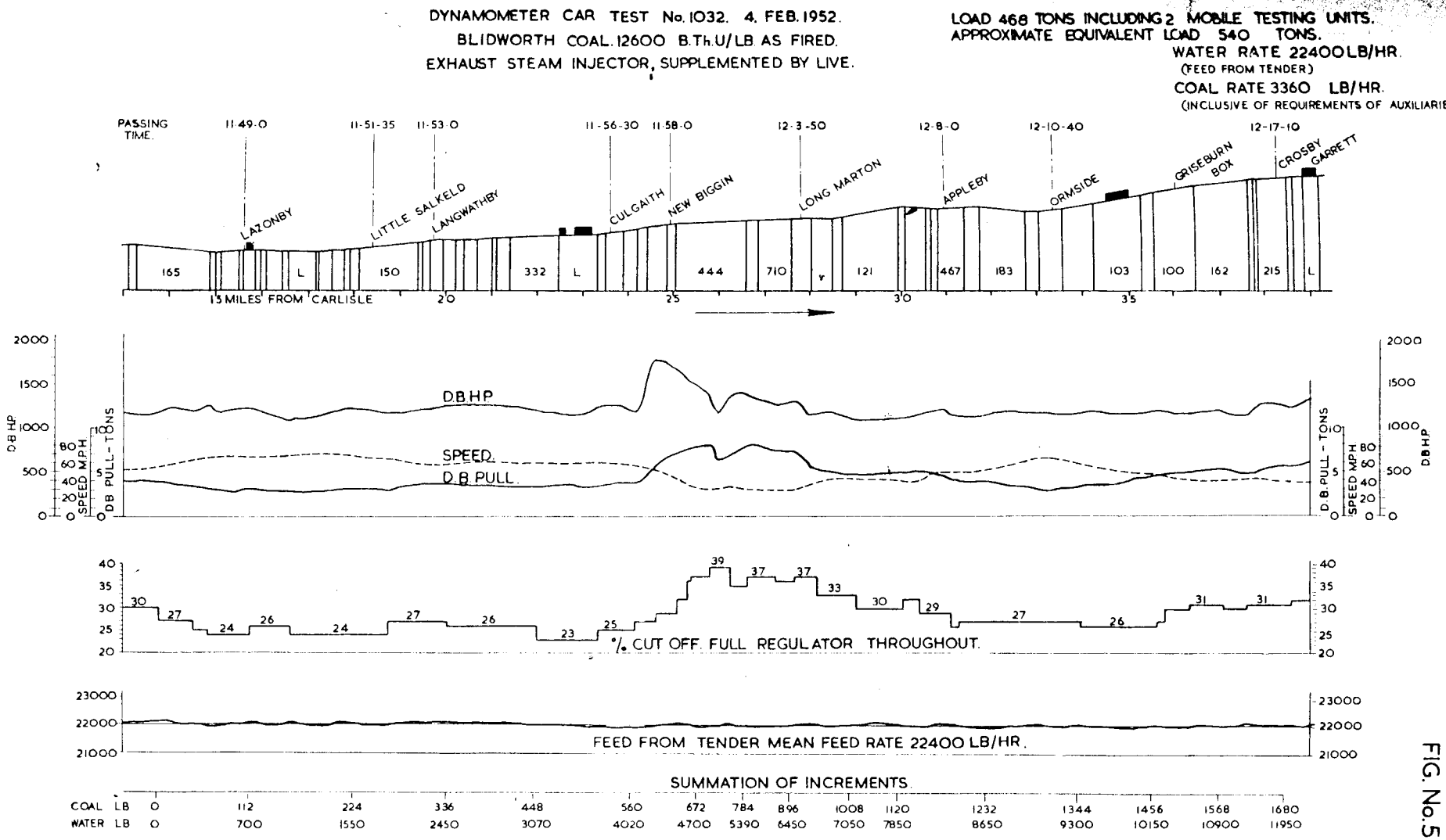


FIG. No. 5

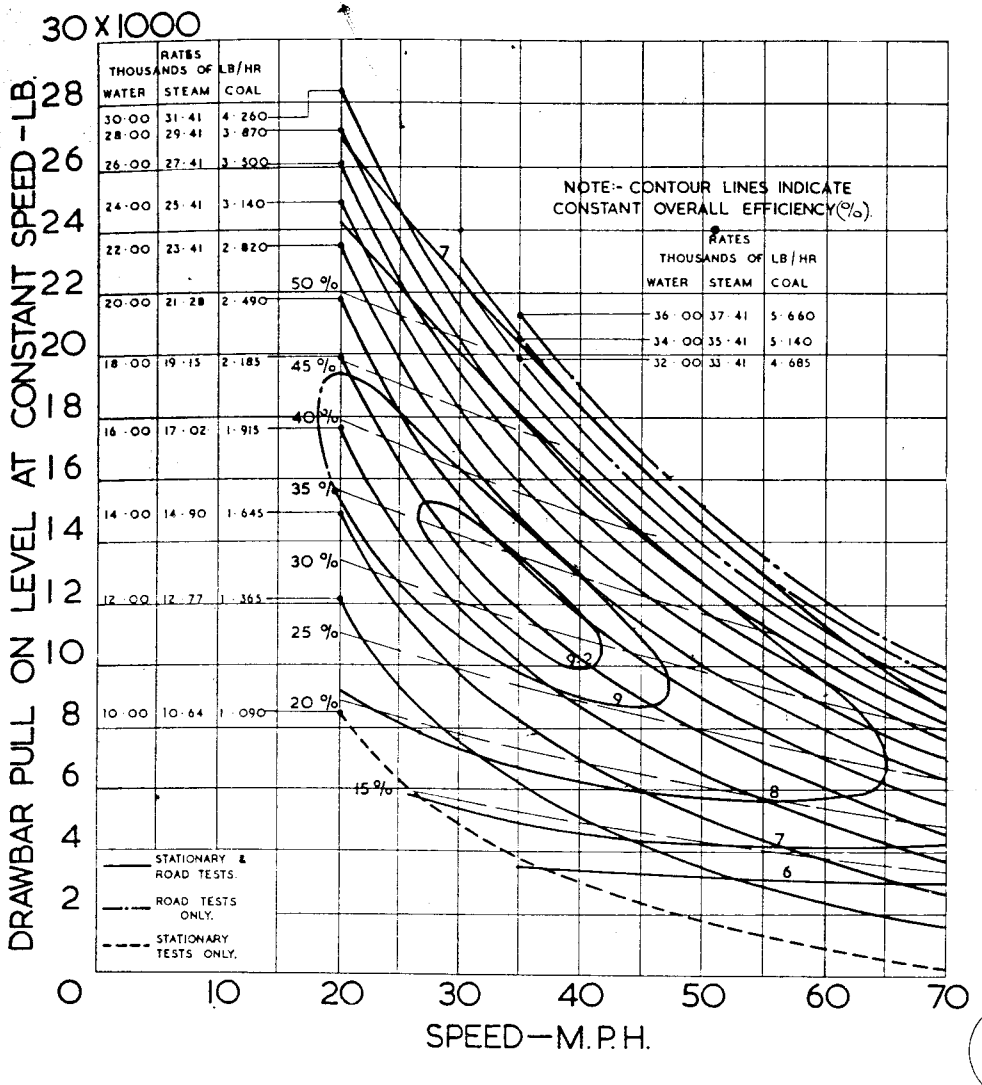
SOUTH KIRKBY COAL

Performance data : Graphs 1 to 8

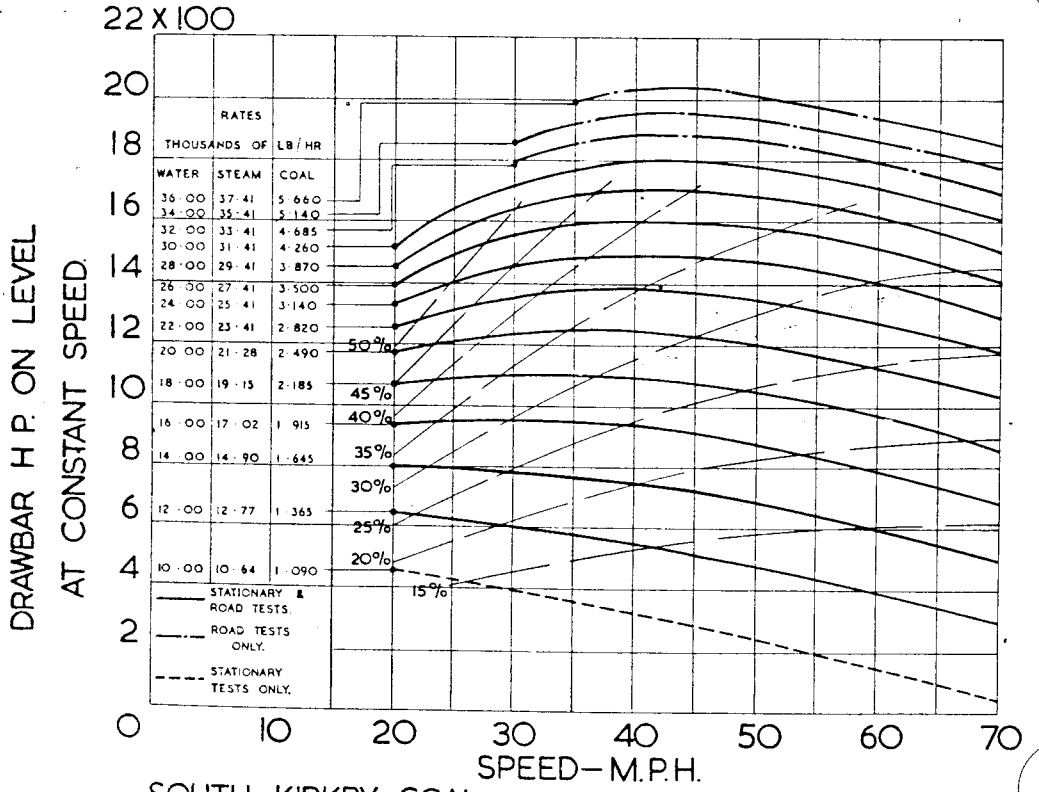
Design data : Graphs 9 to 21

INJECTOR AT HIGHER RATES.

CUT-OFFS SHOWN REFER TO MAXIMUM STEAM CHEST PRESSURE.



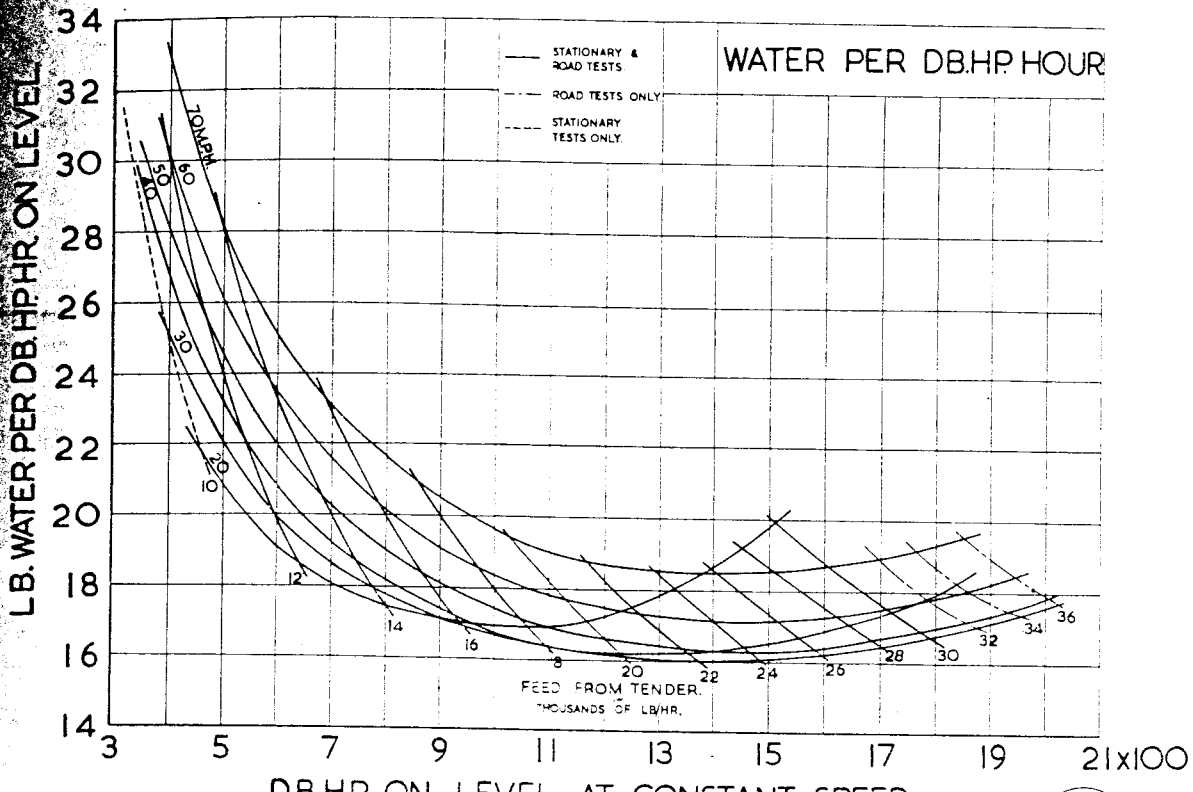
1



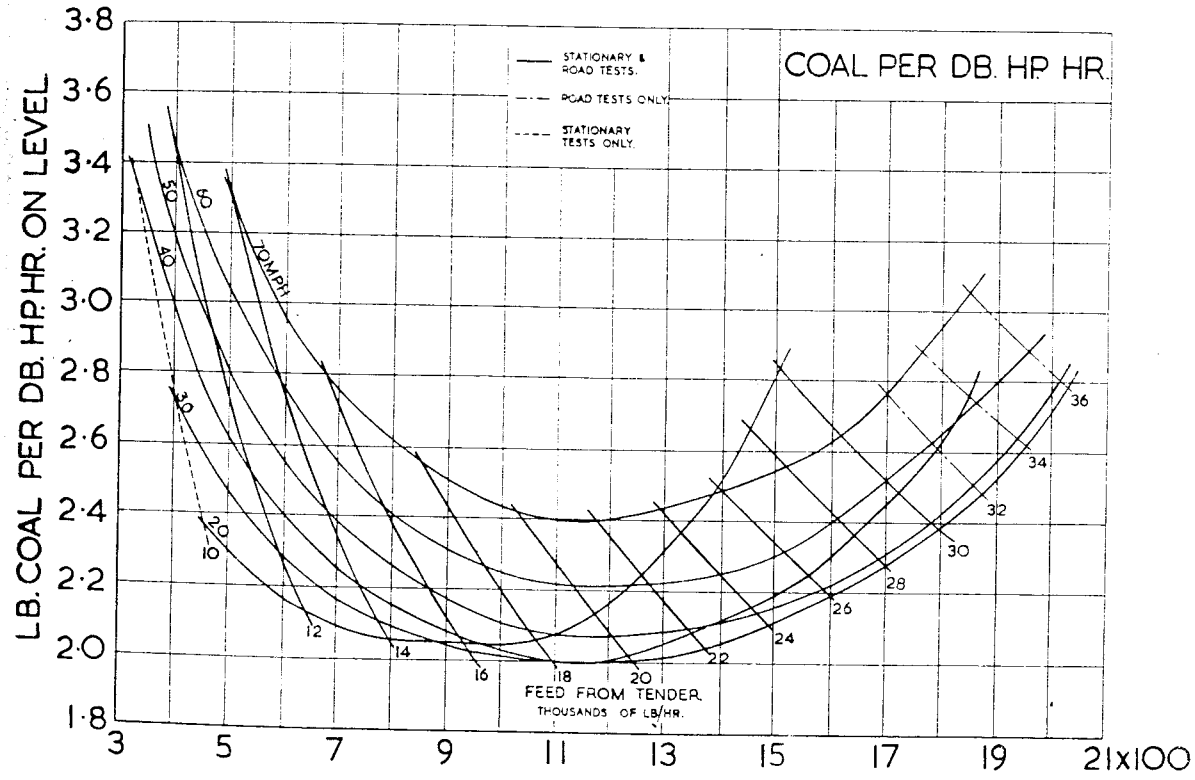
2

SOUTH KIRKBY COAL.
13800 B. Th.U/LB.

DRAWBAR CHARACTERISTICS.



3



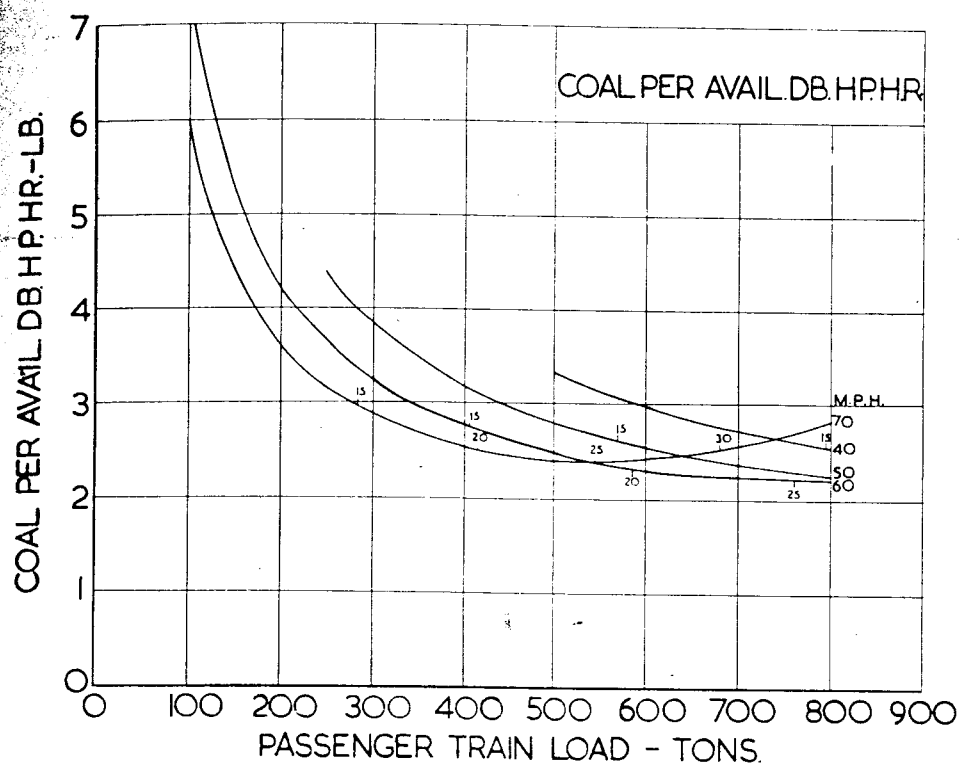
4

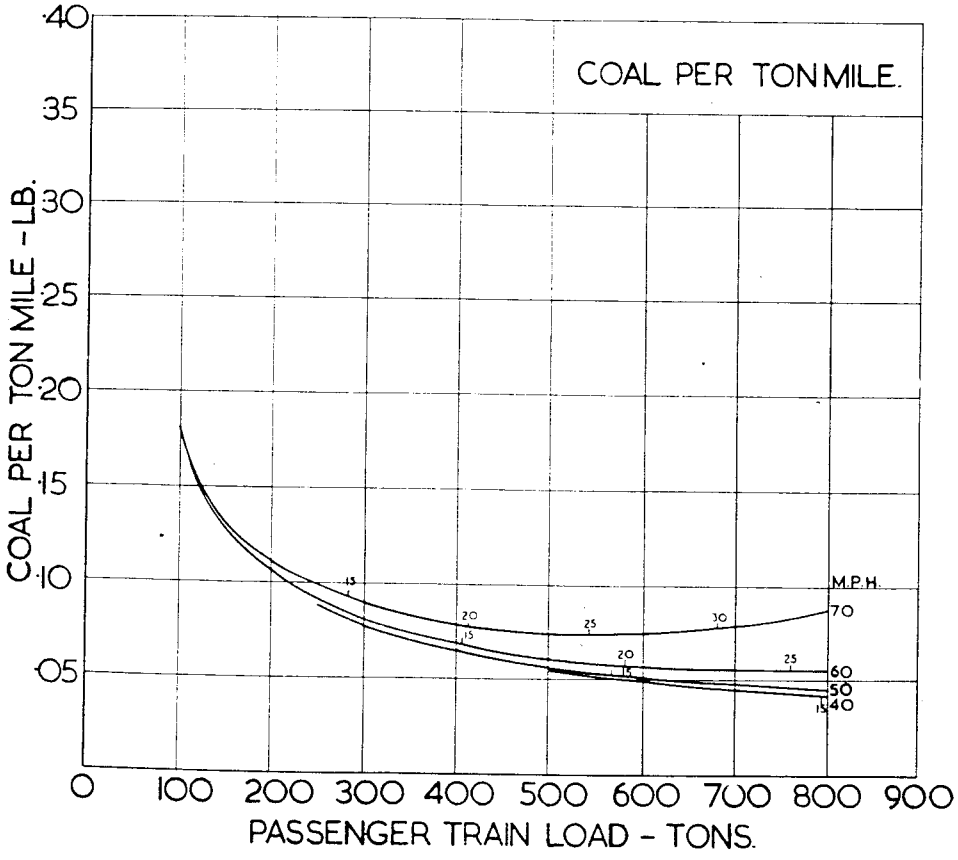
SOUTH KIRKBY COAL.
13800 B.Th.U/LB.

WATER & COAL PER DB.HP HR.

SOUTH KIRBY COAL 13800 B.Th.U/LB.

SMALL FIGURES ON CURVES INDICATE CUT-OFF, MAX STEAM CHEST PRESSURE.





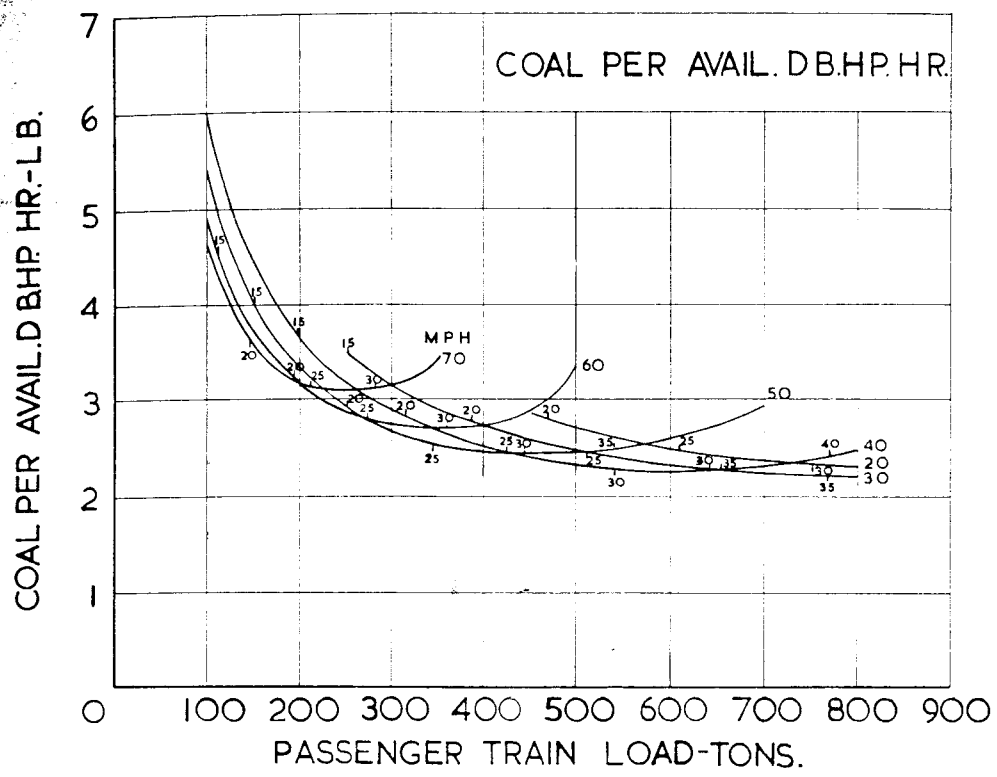
PASSENGER SERVICE - LEVEL.

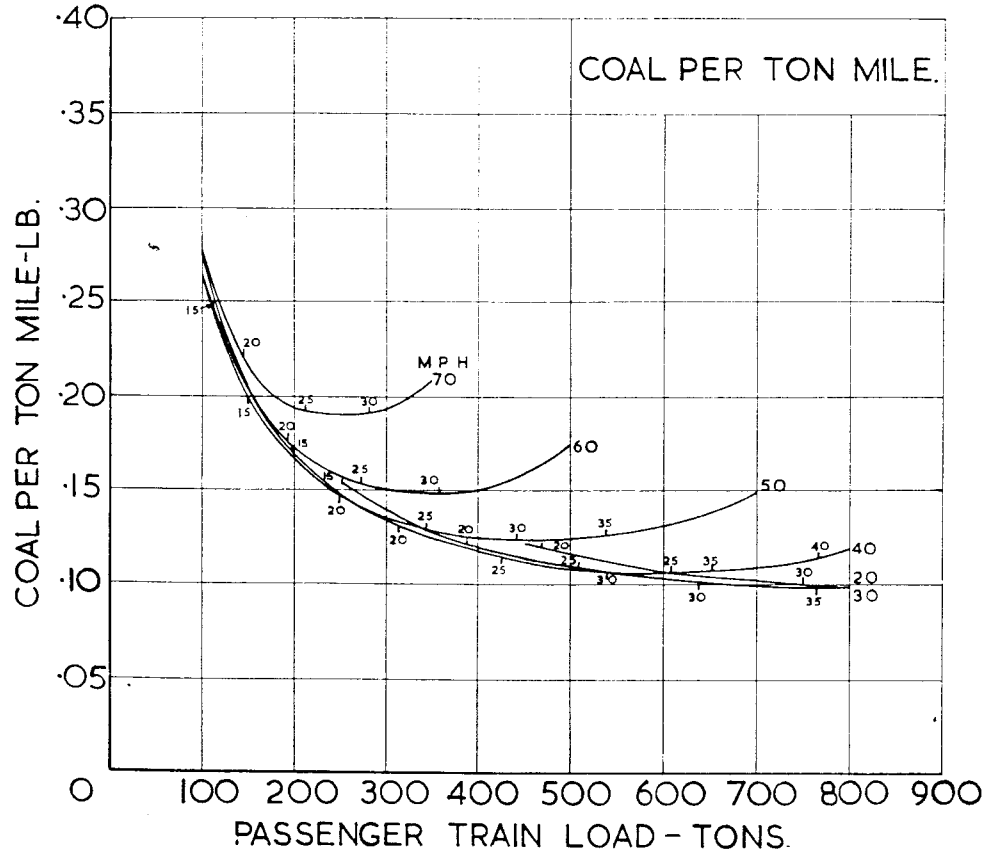
5

EXAMPLE OF COST IN COAL OF DIFFERENT TRAIN LOADS & SPEEDS.

SOUTH KIRKBY COAL 13800 B.Th. U./LB.

SMALL FIGURES ON CURVES INDICATE CUT-OFF, MAX STEAM CHEST PRESSURE.



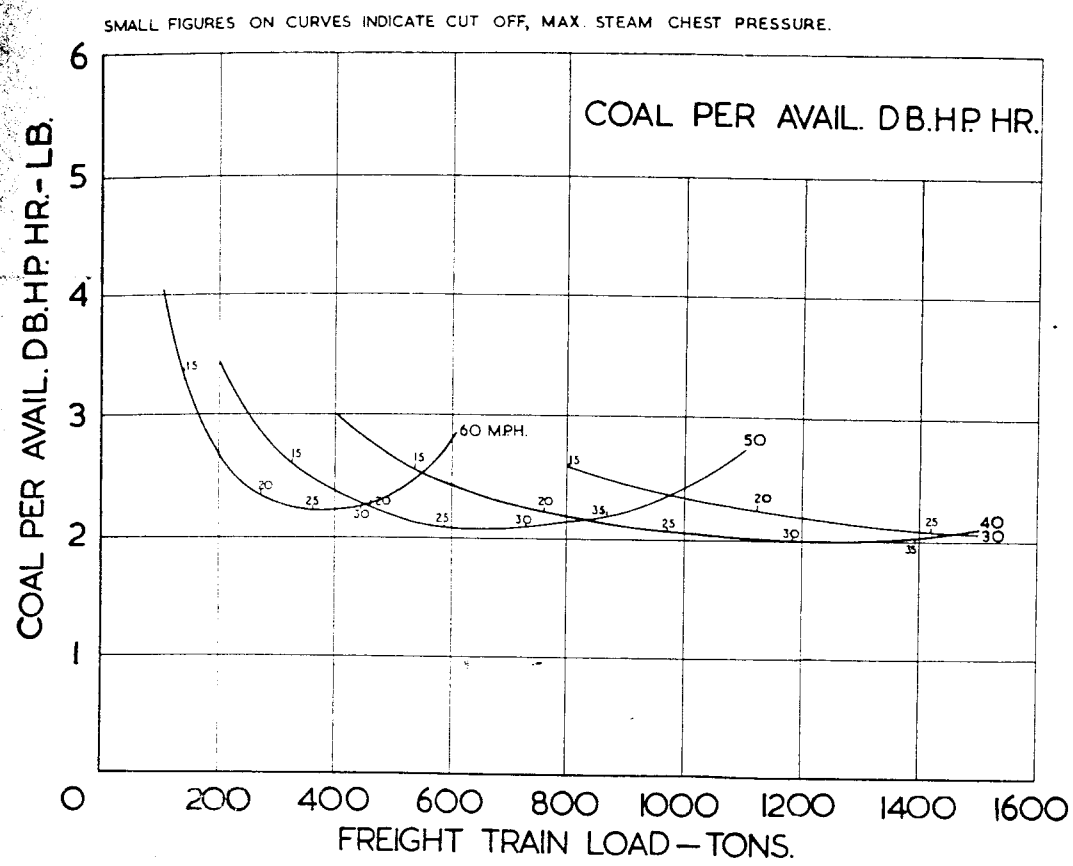


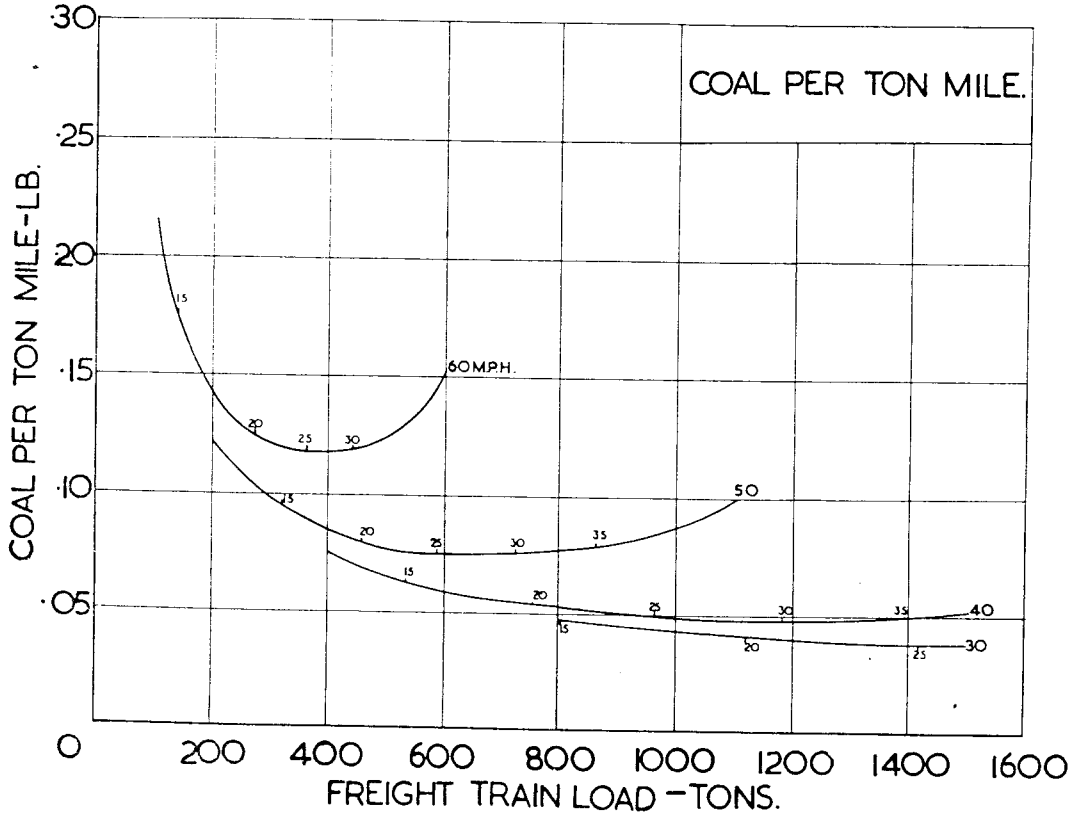
PASSENGER SERVICE-1 IN 200 RISING.

EXAMPLE OF COST IN COAL OF DIFFERENT TRAIN LOADS & SPEEDS.

6

SOUTH KIRKBY COAL 13800 B. Th. U/LB.





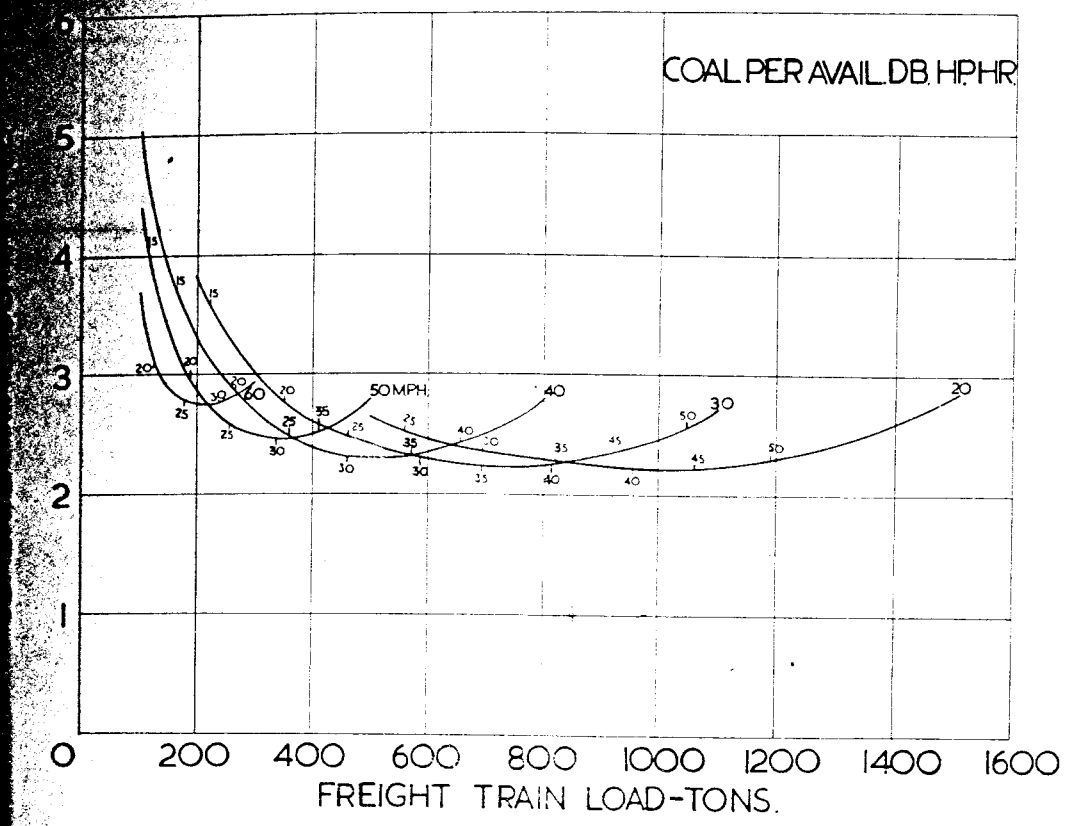
7

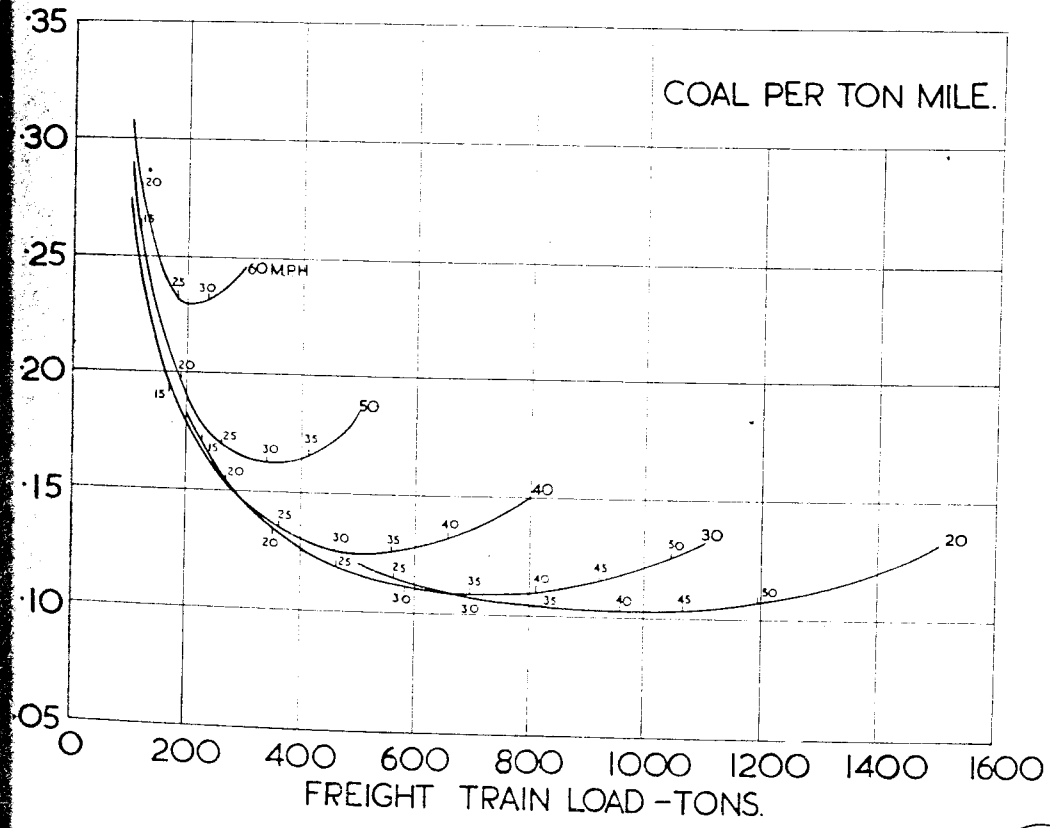
FREIGHT SERVICE-LEVEL.

EXAMPLE OF COST IN COAL OF DIFFERENT TRAIN LOADS & SPEEDS.

SOUTH KIRBY COAL 13800 B.Th.U./LB.

SMALL FIGURES ON CURVES INDICATE CUT OFF, MAX STEAM CHEST PRESSURE.

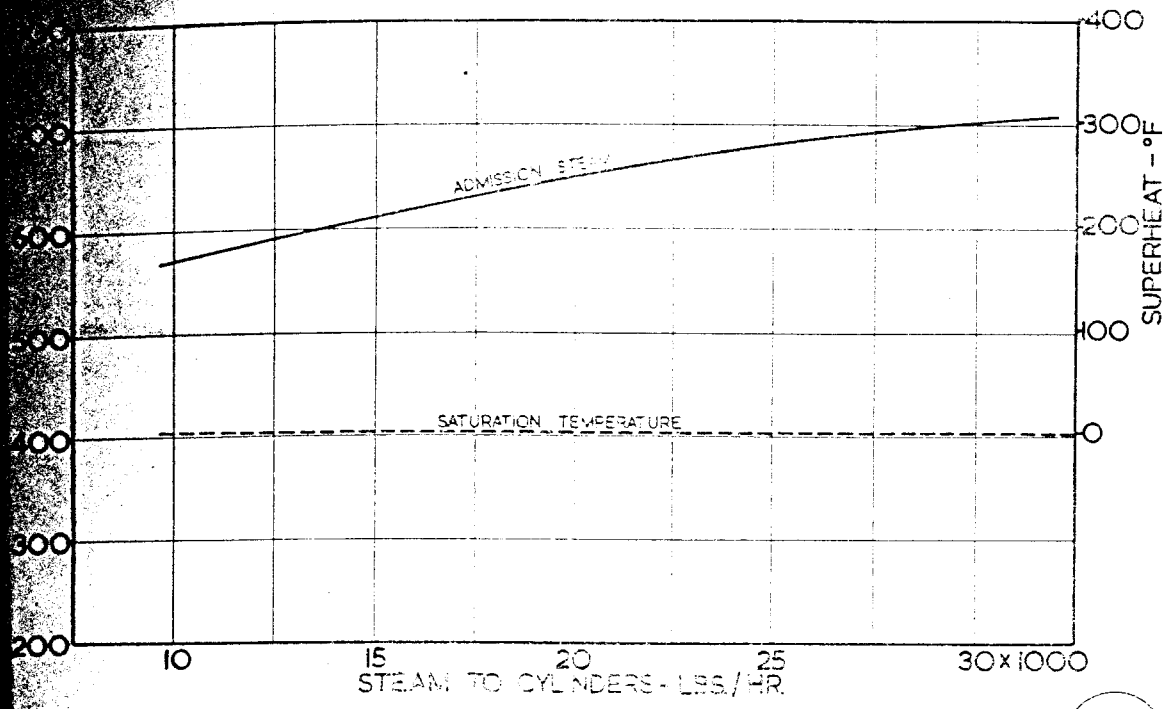




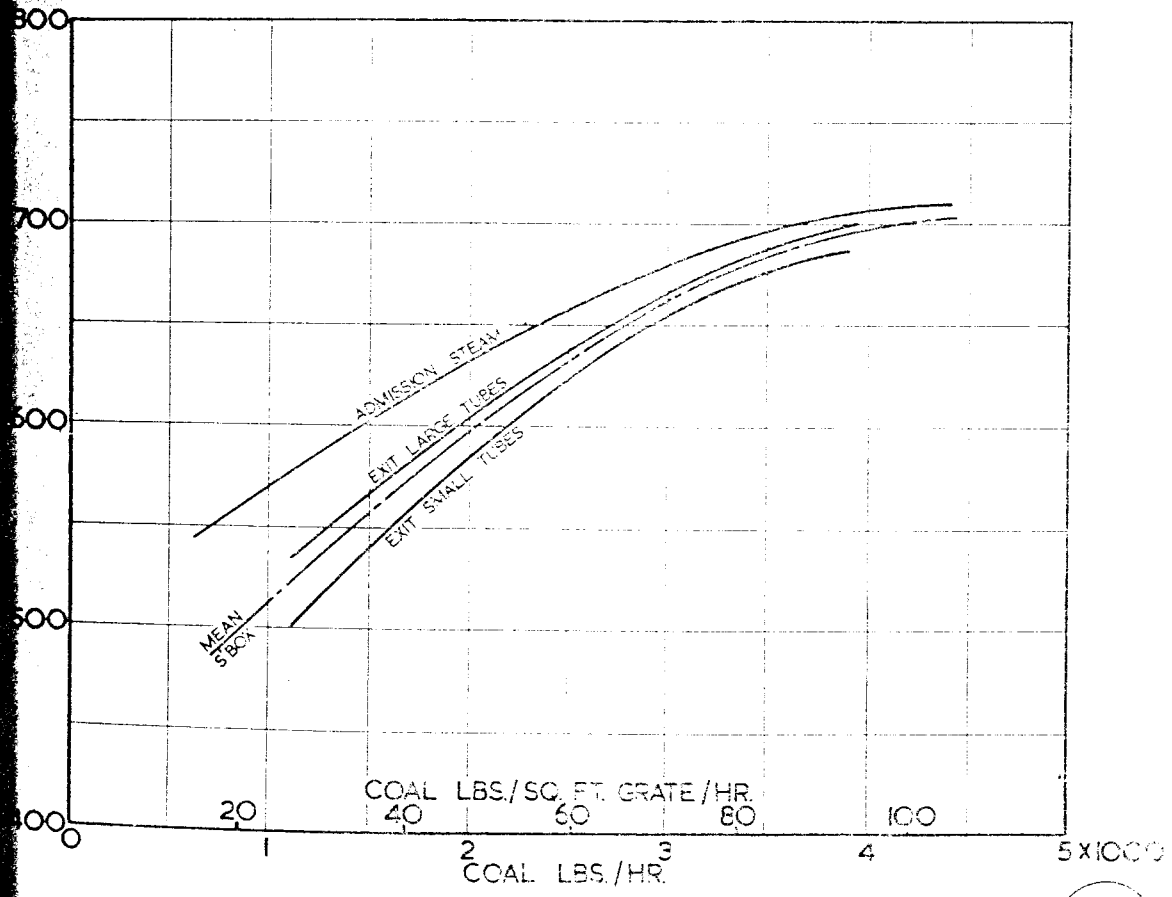
FREIGHT SERVICE-1 IN 200 RISING.

EXAMPLE OF COST IN COAL OF DIFFERENT TRAIN LOADS & SPEEDS.

8



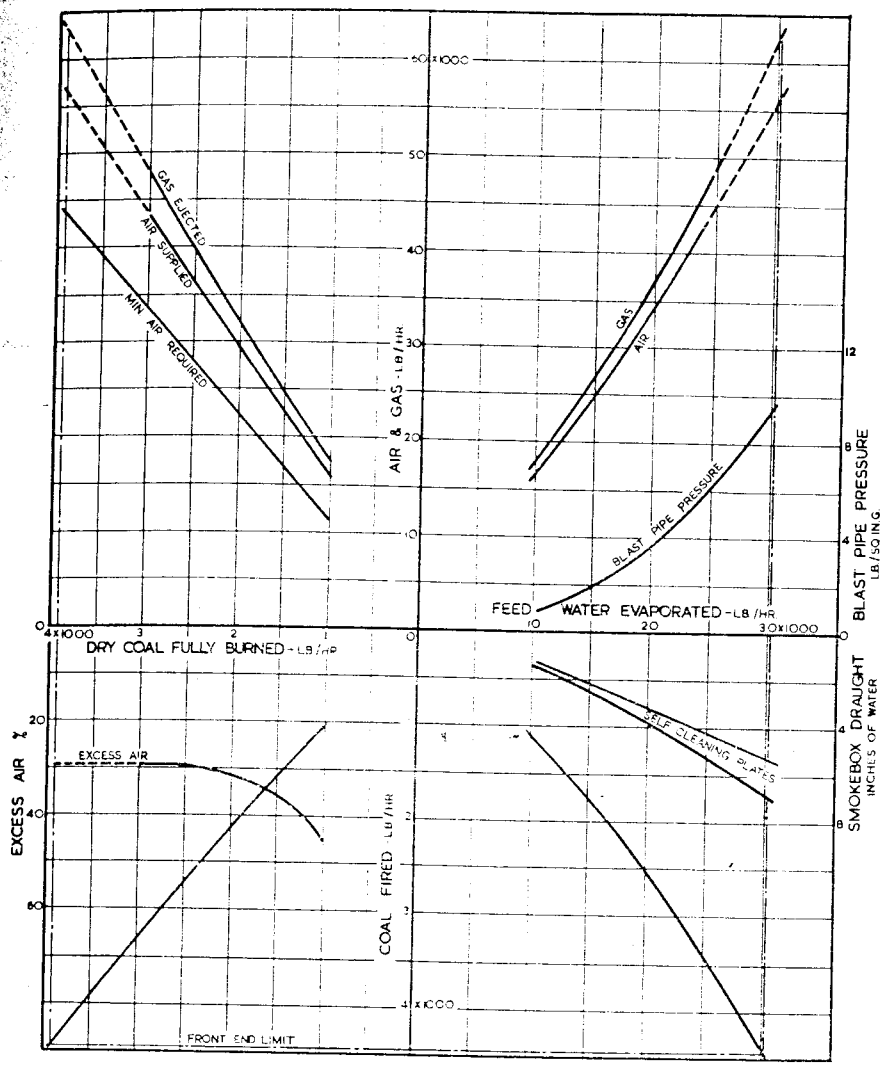
9



SOUTH KIRKBY COAL - 13,800 B.TH.U./LB.
EXHAUST STEAM INJECTOR.

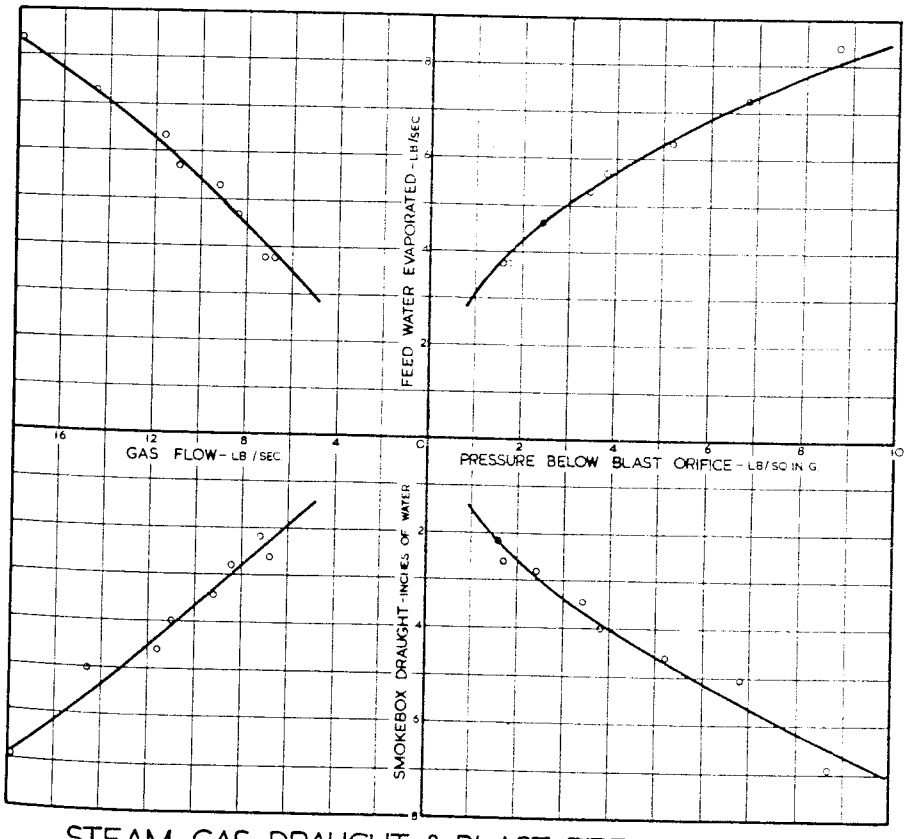
10

TEMPERATURES



STEAM-AIR-COMBUSTION

11

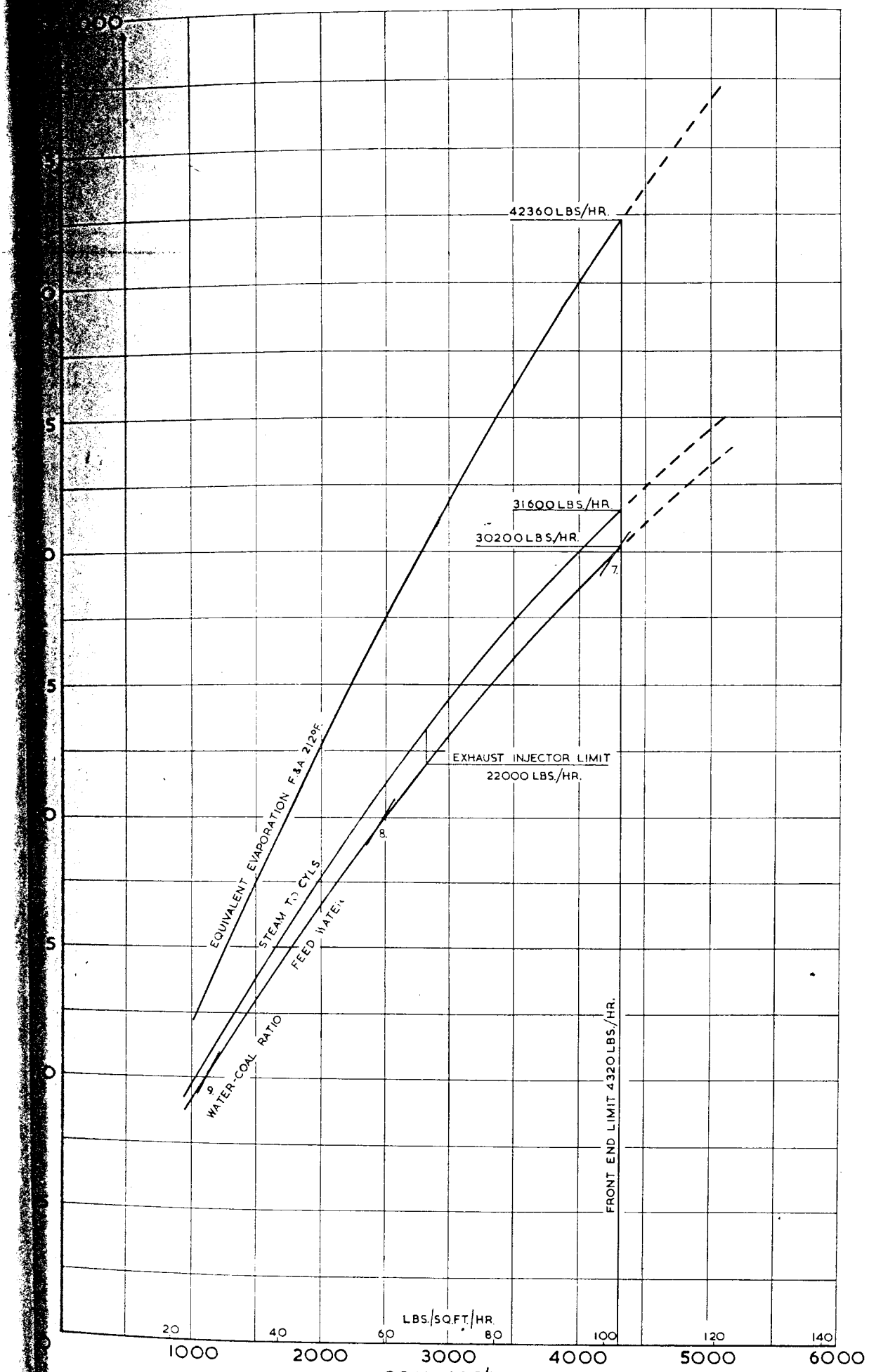


STEAM-GAS-DRAUGHT & BLAST PIPE PRESSURE

12

SOUTH KIRKBY COAL - 13,800 B.TH.U./LB.

EXHAUST STEAM INJECTOR



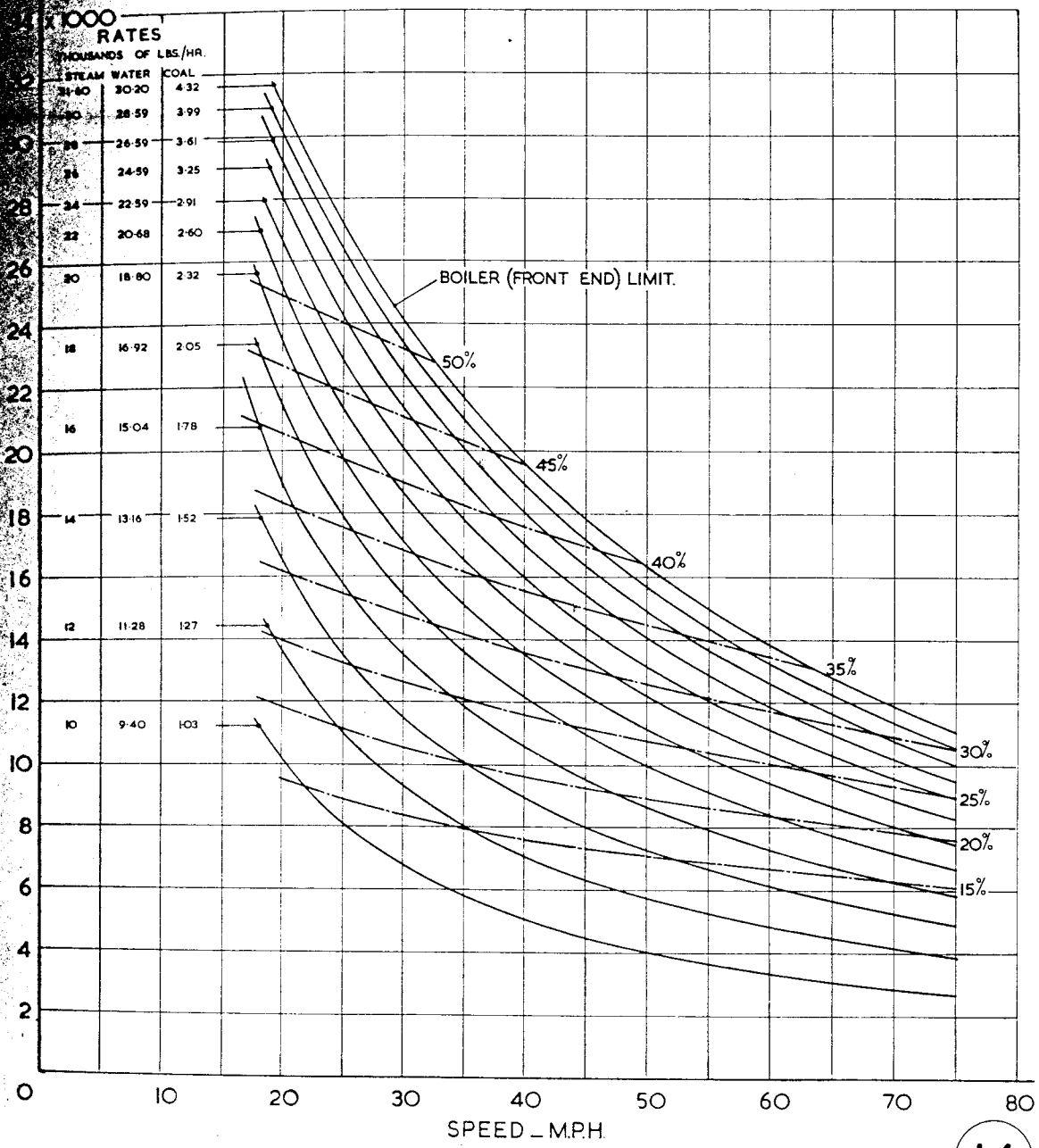
SOUTH KIRKBY COAL C.V. 13800 B.T.H.U. LB.

EXHAUST STEAM INJECTOR

EVAPORATION

13

CUT OFFS SHOWN REFER TO MAXIMUM STEAM CHEST PRESSURE.
RATED TRACTIVE EFFORT 32150 LBS.

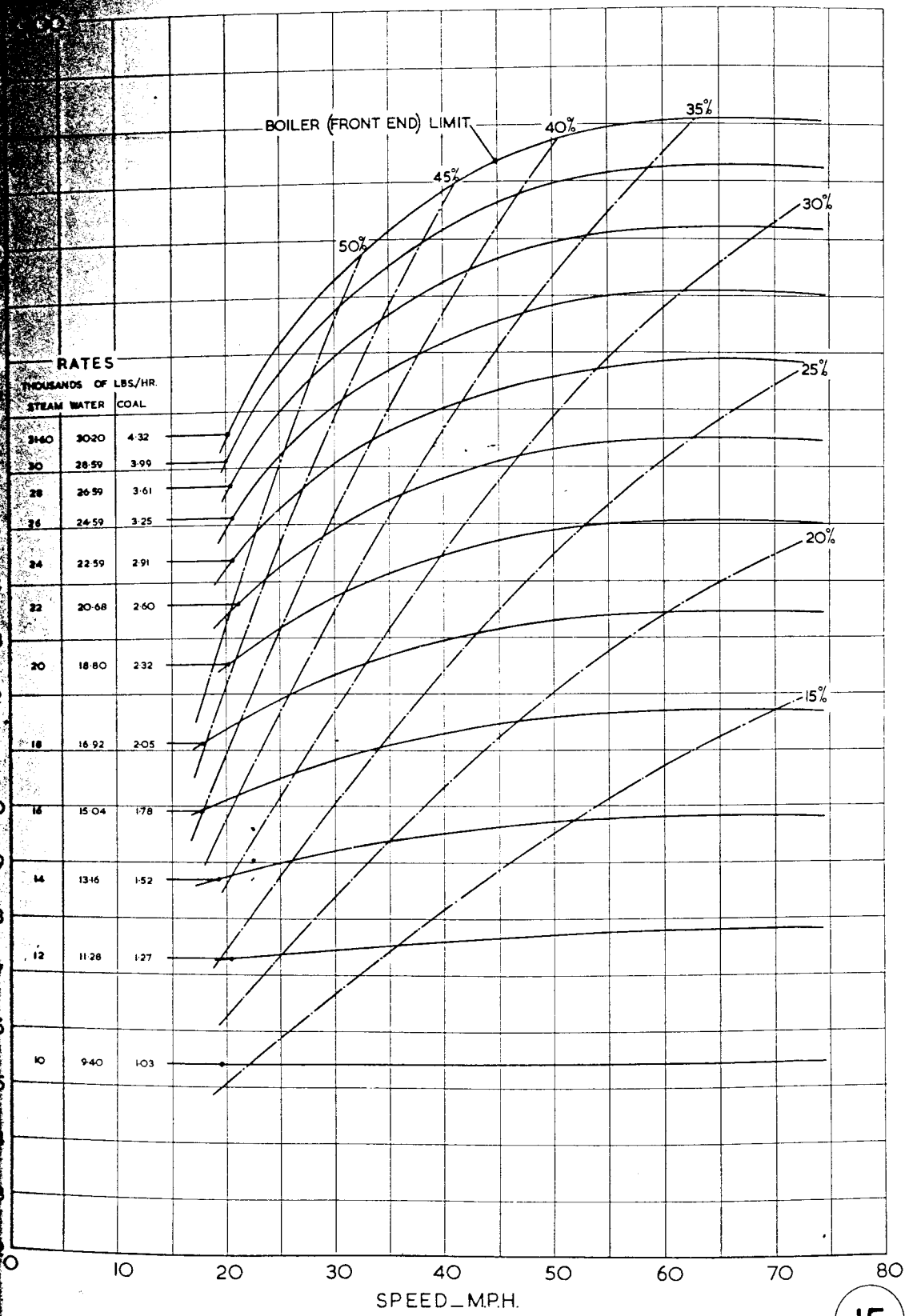


SOUTH KIRKBY COAL – 13800 B.Th.U./LB.
EXHAUST STEAM INJECTOR.

14

INDICATED TRACTIVE EFFORT CHARACTERISTICS

CUT OFFS SHOWN REFER TO MAXIMUM STEAM CHEST PRESSURE

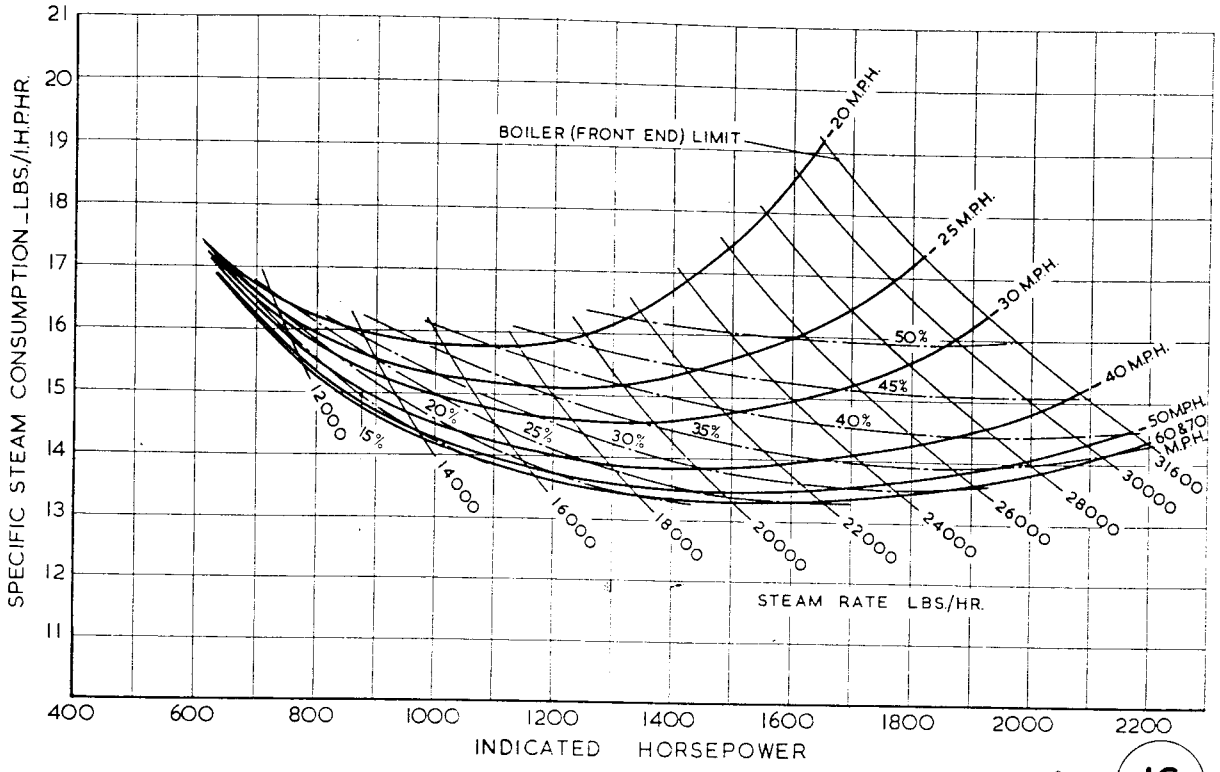


SOUTH KIRKBY COAL_13800 B.Th.U./LB.

EXHAUST STEAM INJECTOR

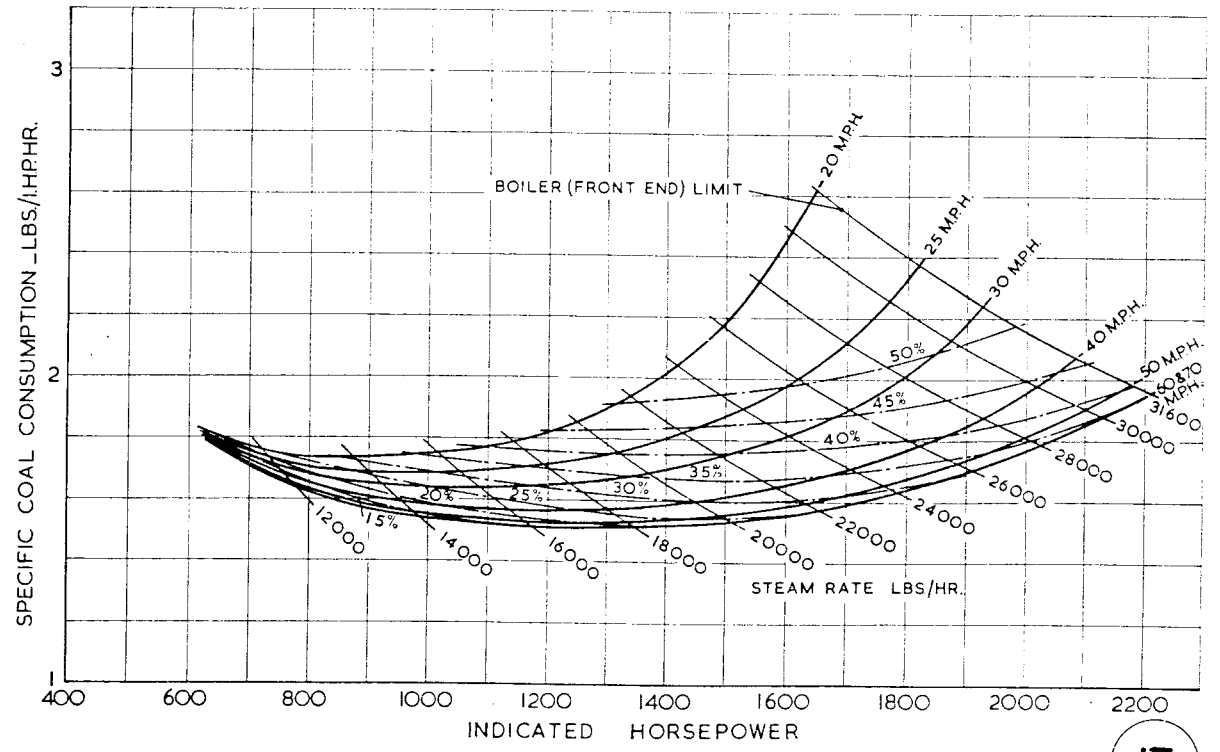
15.

INDICATED HORSEPOWER CHARACTERISTICS



16

CUT OFFS SHOWN REFER TO MAXIMUM STEAM CHEST PRESSURE

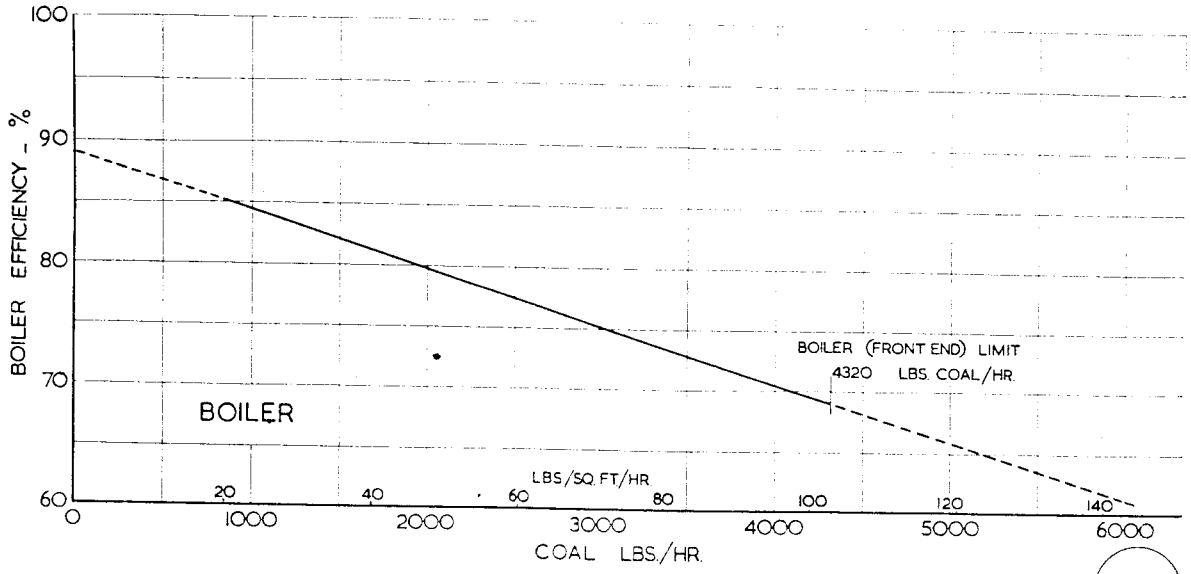


17

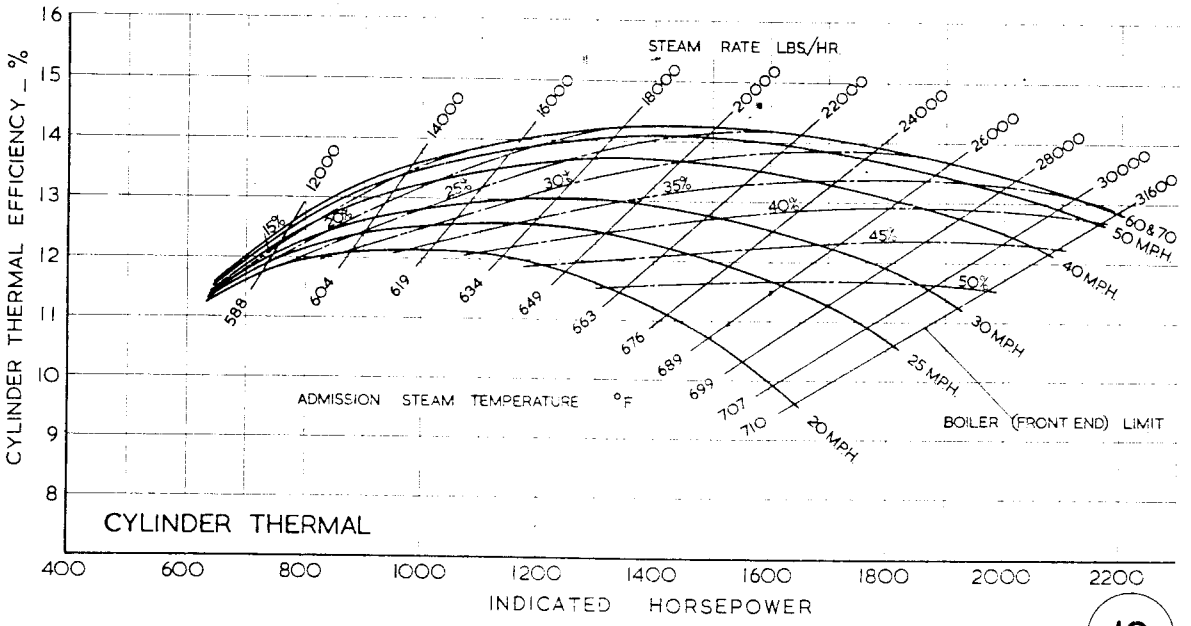
SOUTH KIRKBY COAL_13800 B.Th.U./LB.

EXHAUST STEAM INJECTOR

STEAM & COAL PER I.H.P. HR.

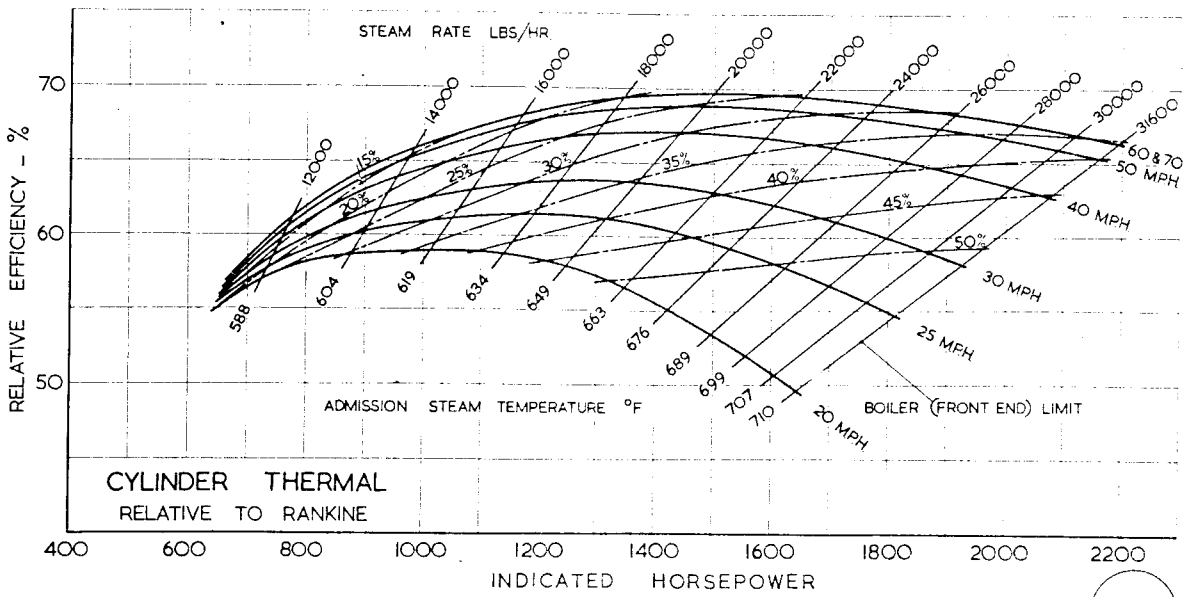


18



19

CUT OFFS SHOWN REFER TO MAXIMUM STEAM CHEST PRESSURE

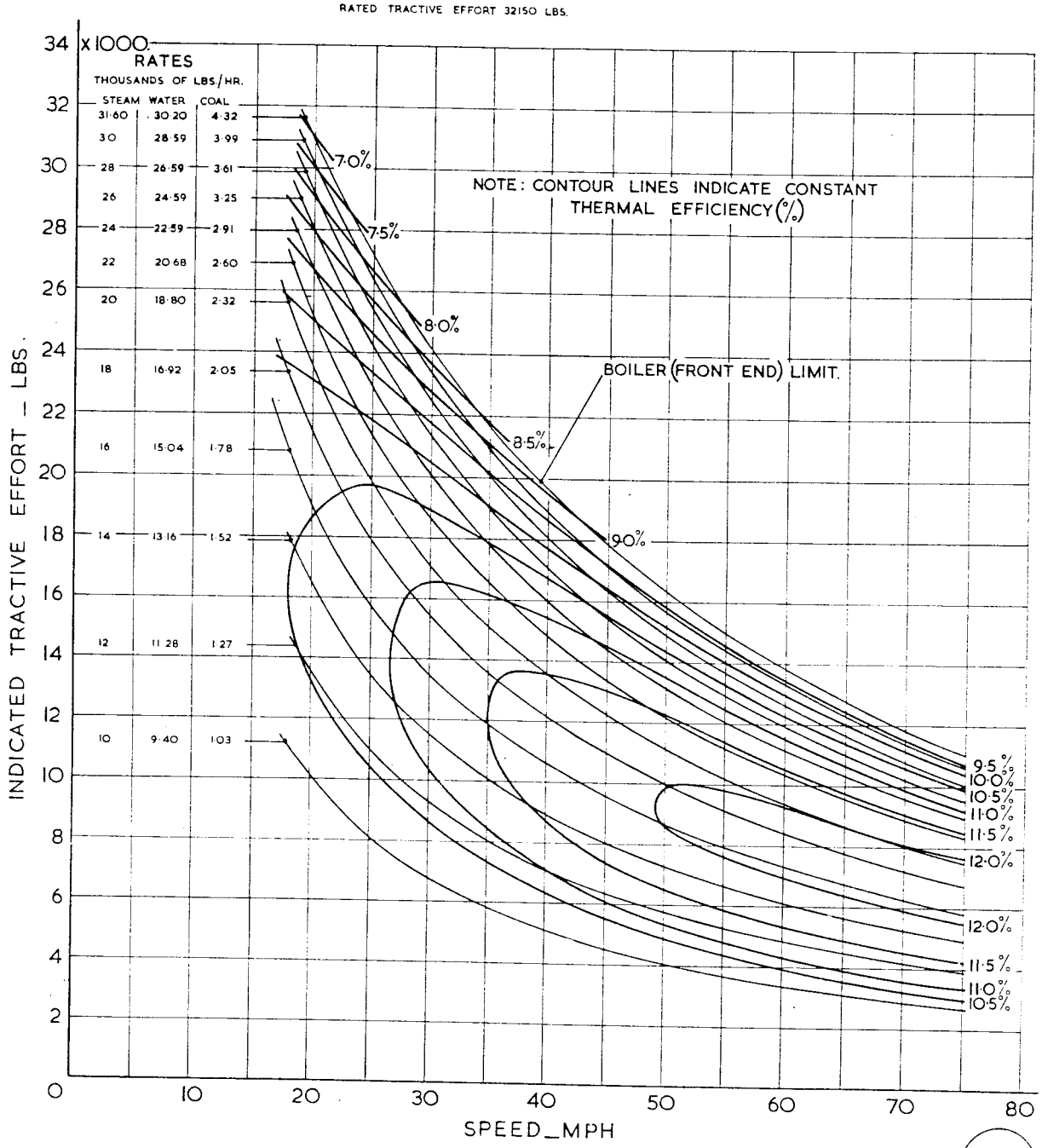


20

SOUTH KIRKBY COAL - 13800 B.Th.U./LB.

EXHAUST STEAM INJECTOR

EFFICIENCIES



SOUTH KIRKBY COAL — 13800 B.Th.U./LB.

EXHAUST STEAM INJECTOR.

21

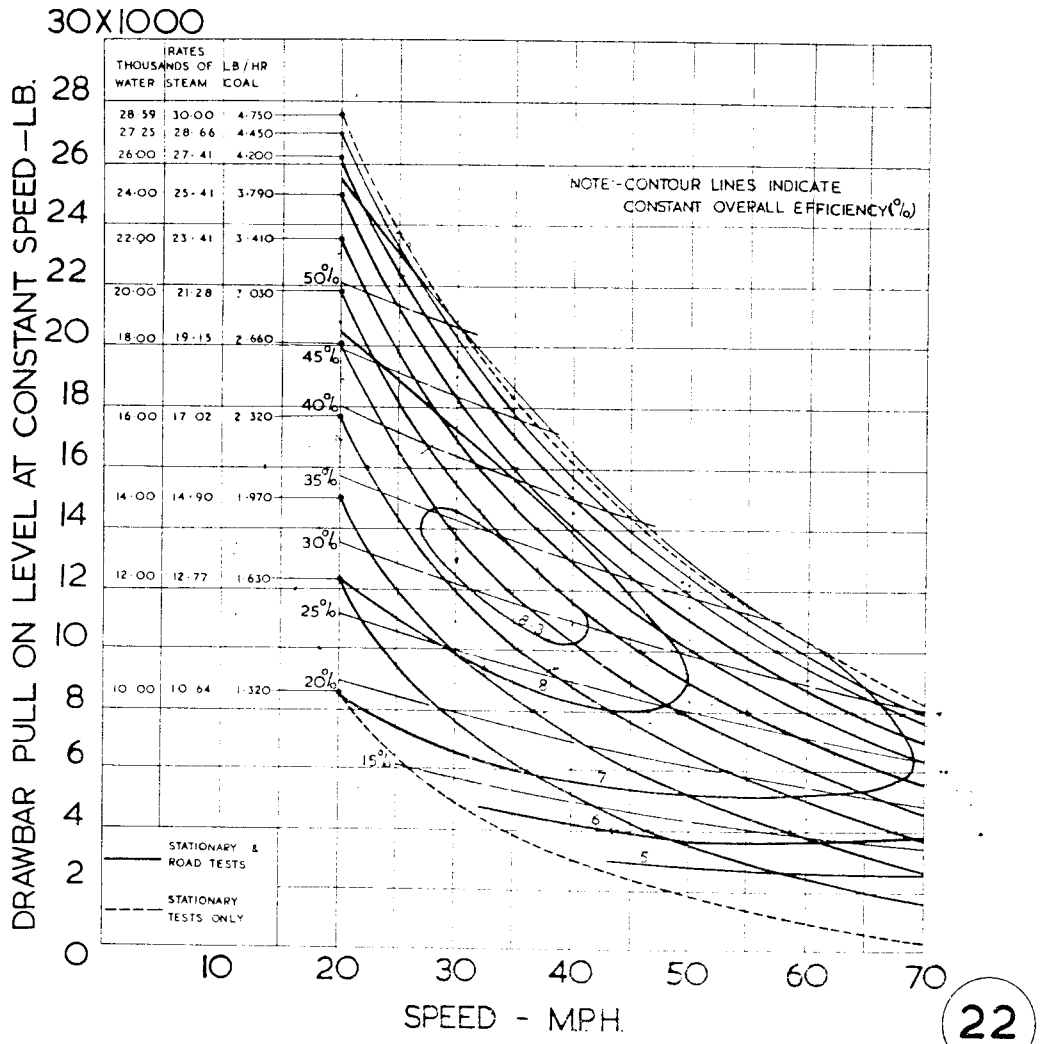
OVERALL EFFICIENCY REFERRED TO CYLINDERS

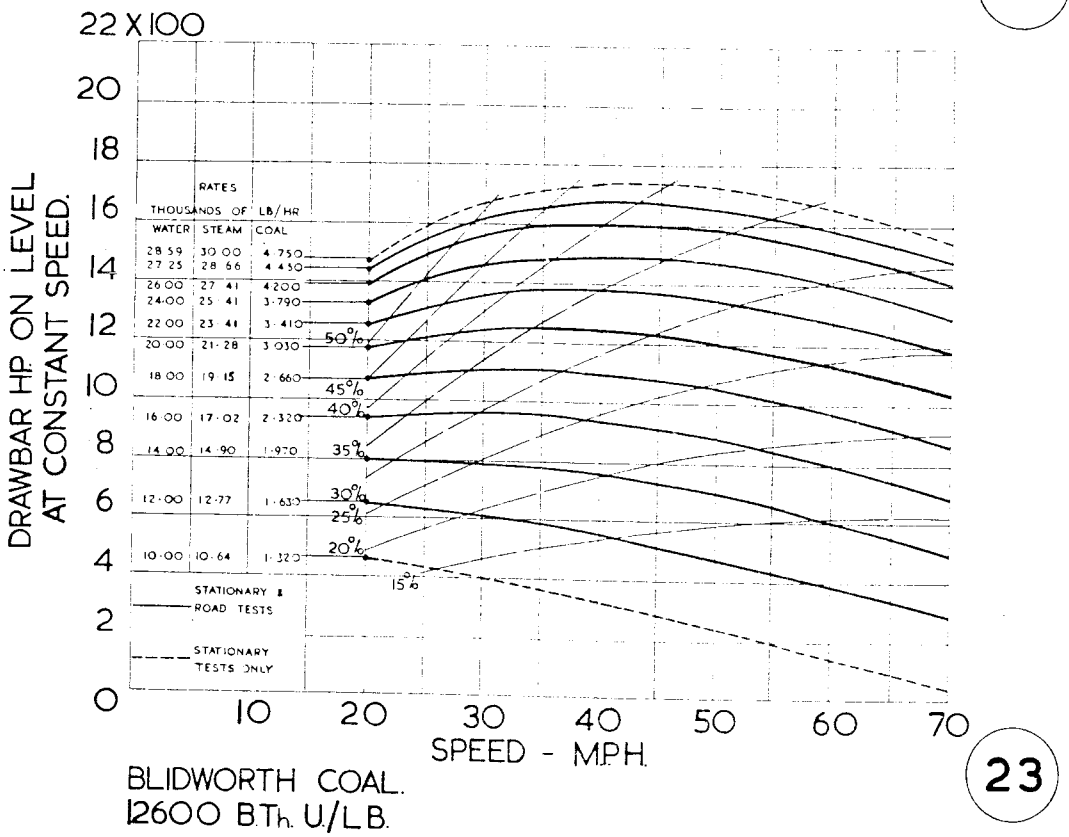
BLIDWORTH COAL.

Performance data : Graphs 22 to 29

Design data : Graphs 30 to 42

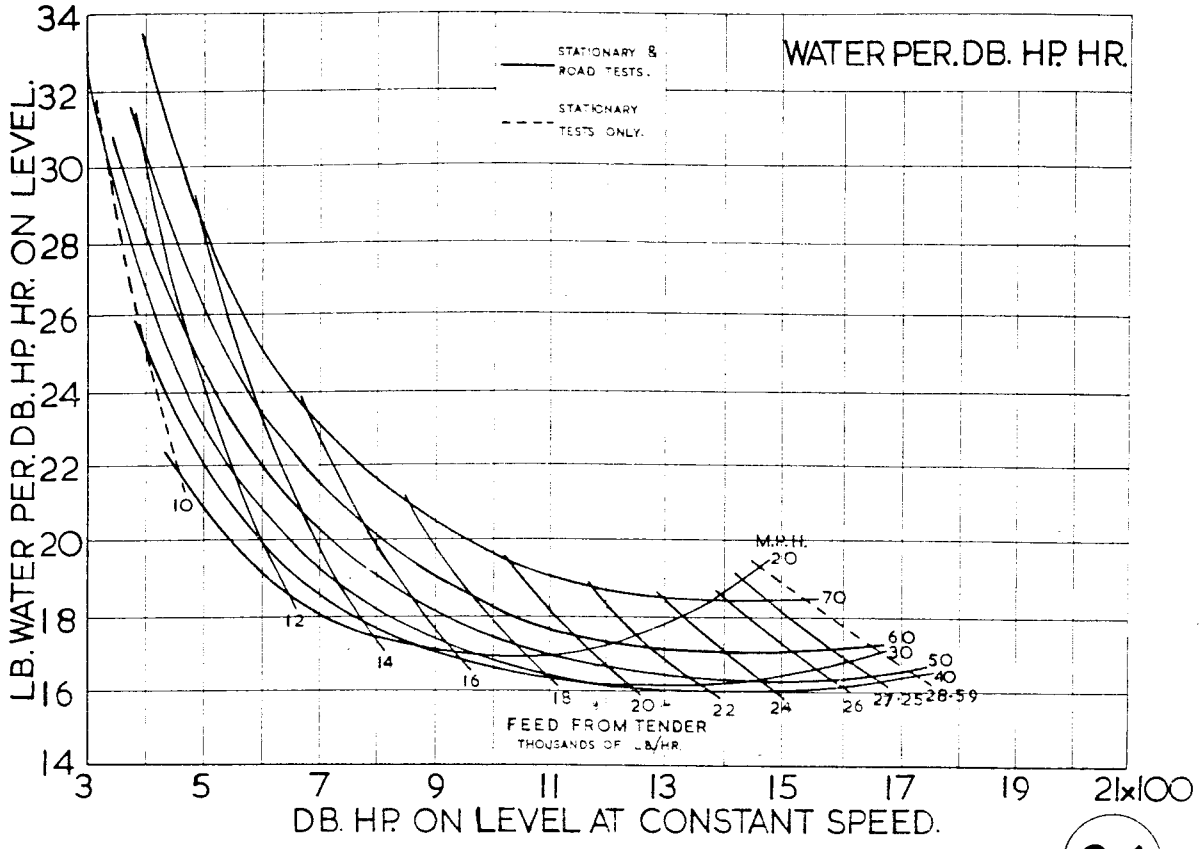
LIMIT OF EXHAUST STEAM INJECTOR 22000 LB/HR SUPPLEMENTED BY LIVE STEAM INJECTOR AT HIGHER RATES.
CUT OFFS SHOWN REFER TO MAXIMUM STEAM CHEST PRESSURE.



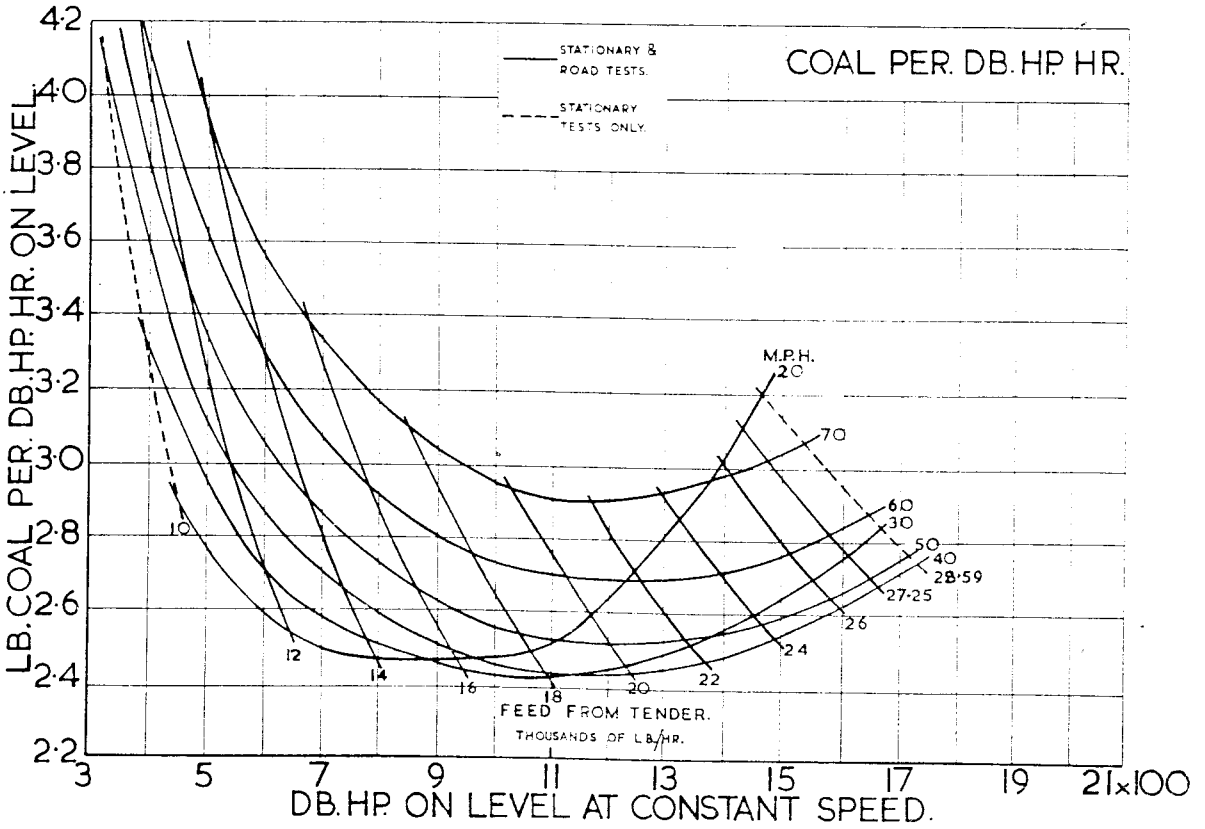


BLIDWORTH COAL.
12600 B.Th. U/L.B.

DRAWBAR CHARACTERISTICS.



24



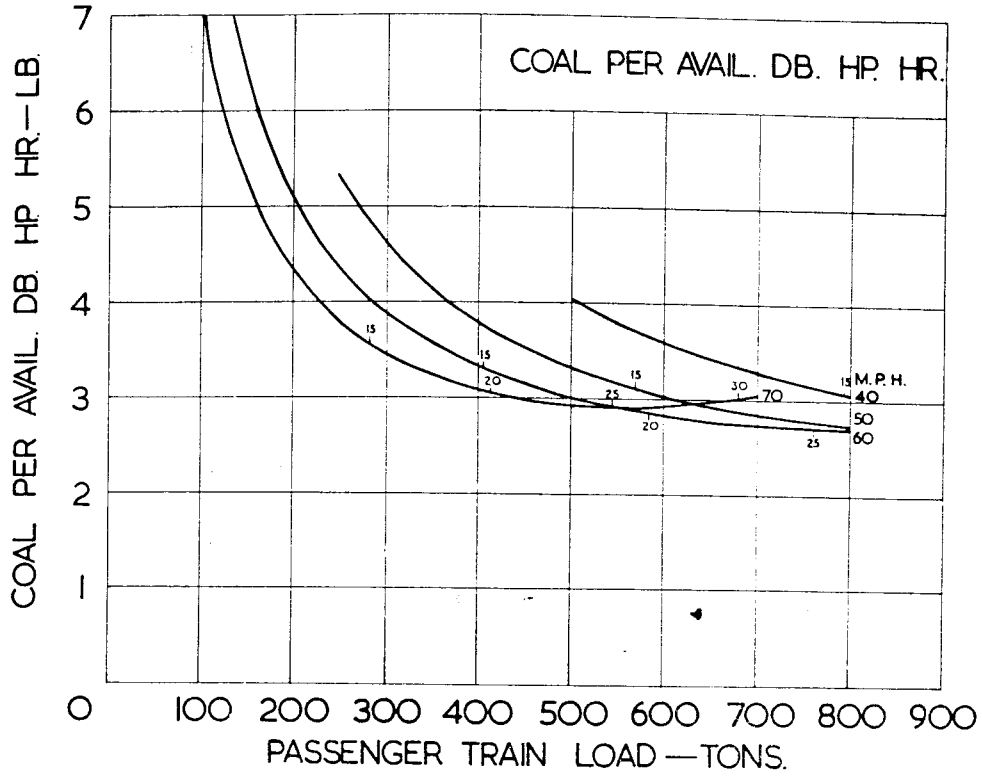
BLIDWORTH COAL
12600 B. Th. U/LB.

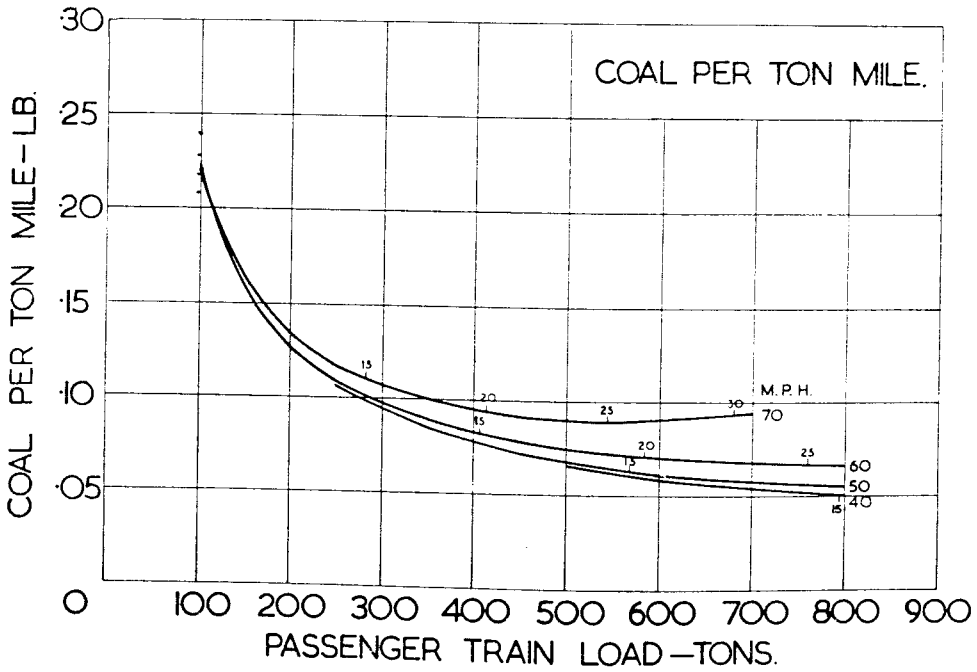
25

WATER & COAL PER DB. HP. HR.

BLIDWORTH COAL 12600 B. Th. U./ LB.

SMALL FIGURES ON CURVES INDICATE CUT OFF, MAX. STEAM CHEST PRESSURE.



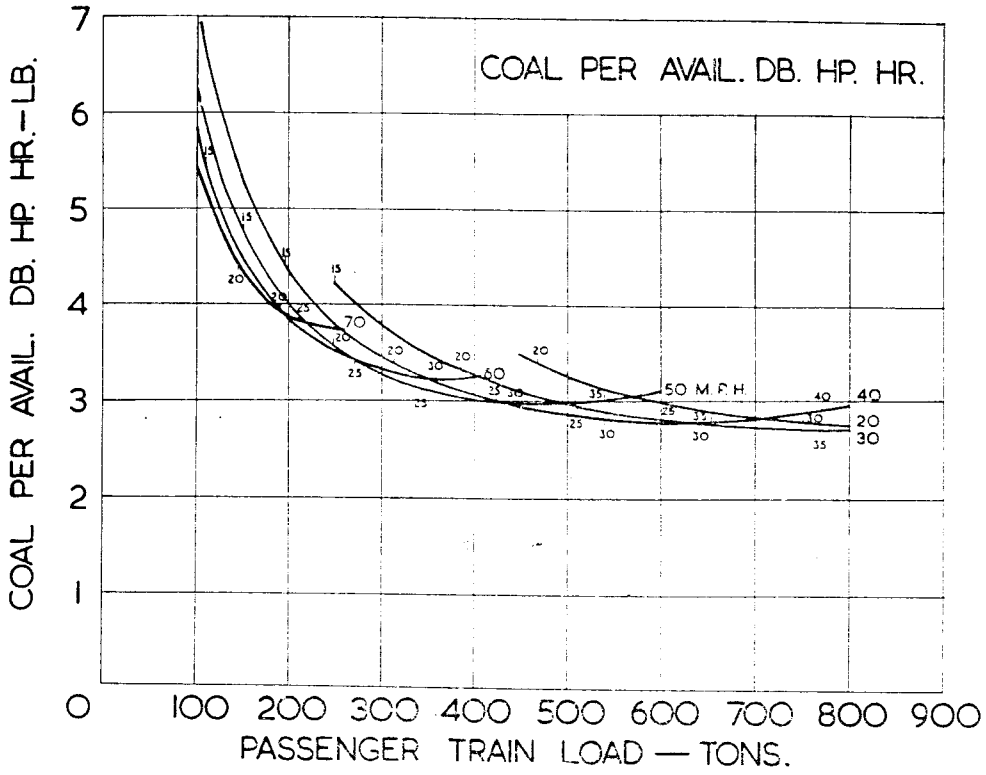


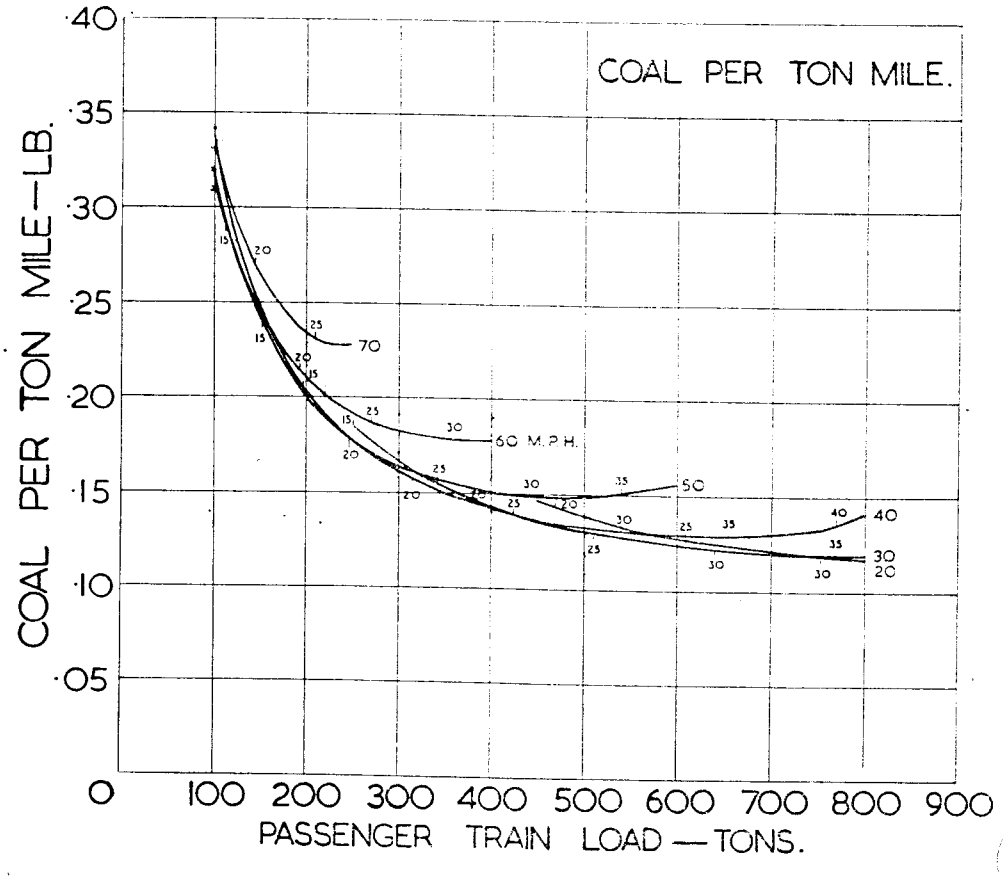
PASSENGER SERVICE—LEVEL.

EXAMPLE OF COST IN COAL OF DIFFERENT TRAIN LOADS & SPEEDS.

BLIDWORTH COAL 12600 B. Th. U./LB.

SMALL FIGURES ON CURVES INDICATE CUT OFF MAX. STEAM CHEST PRESSURE.





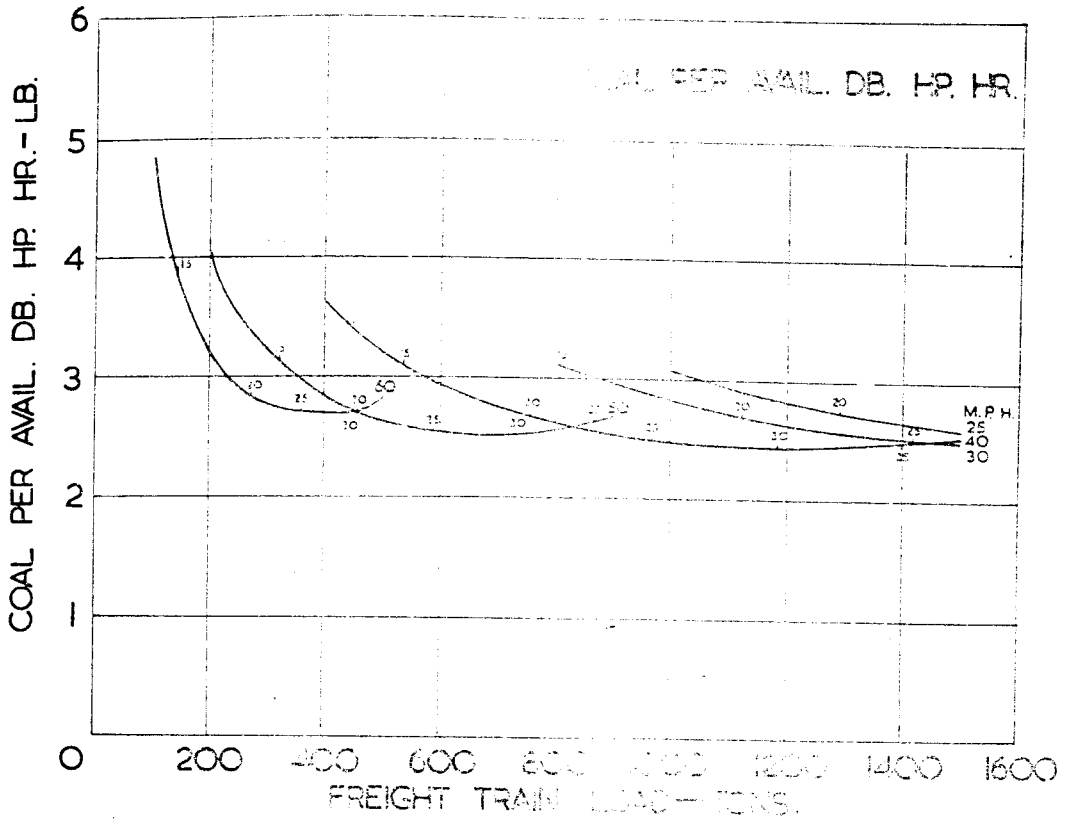
27

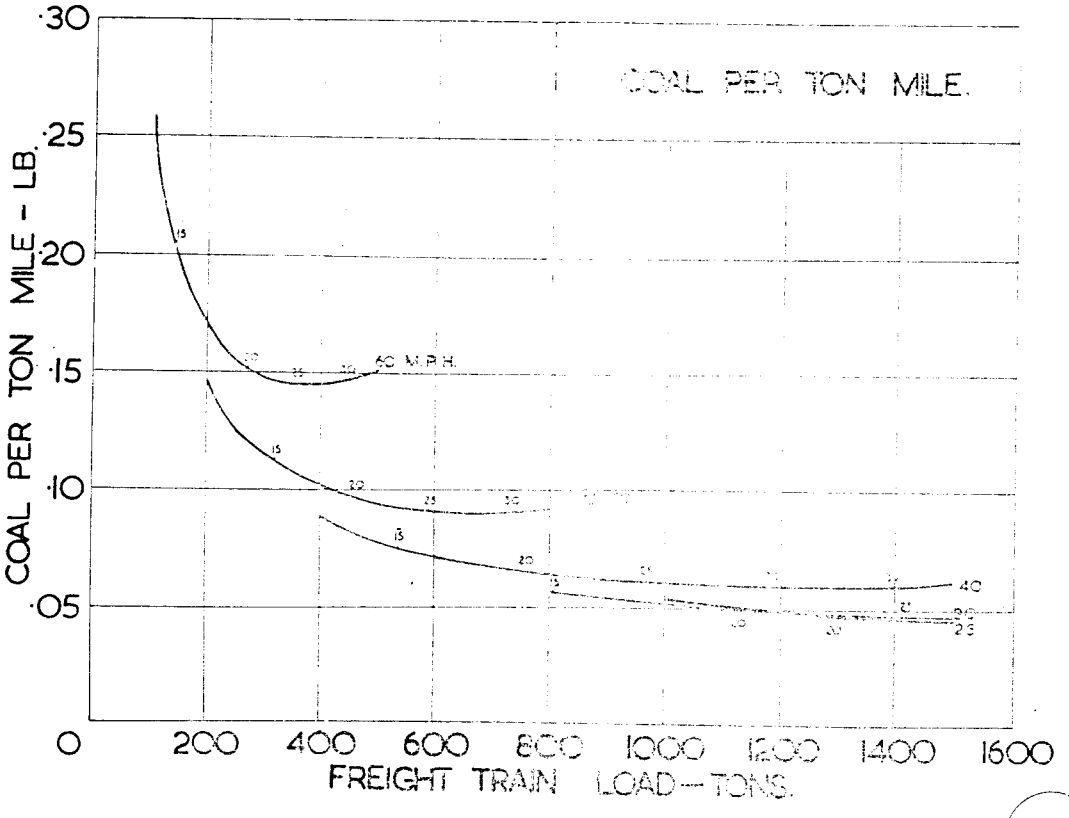
PASSENGER SERVICE—1 IN 200 RISING.

EXAMPLE OF COST IN COAL OF DIFFERENT TRAIN LOADS & SPEEDS.

BLIDWORTH COAL 12,000 B. T. U. / LB.

SMALL FIGURES ON CURVES INDICATE CUT-OFF, MAX. PER CENT. BOILER PRESSURE.





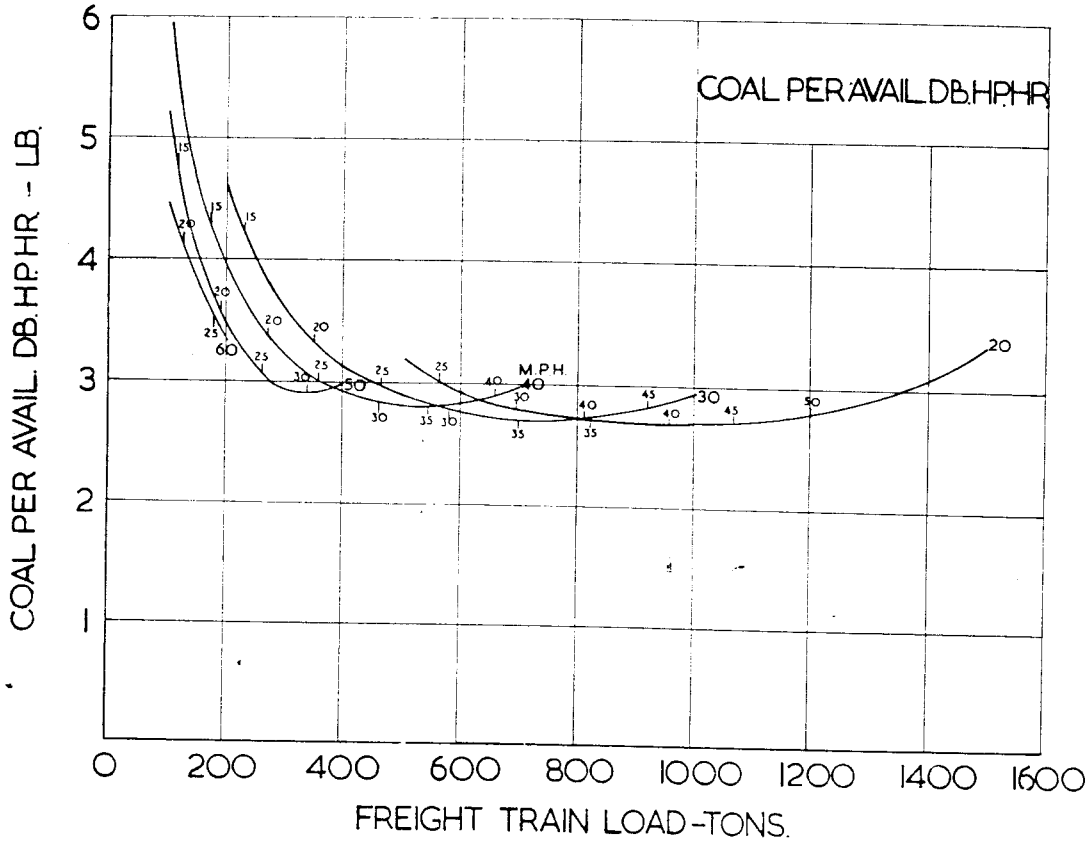
28

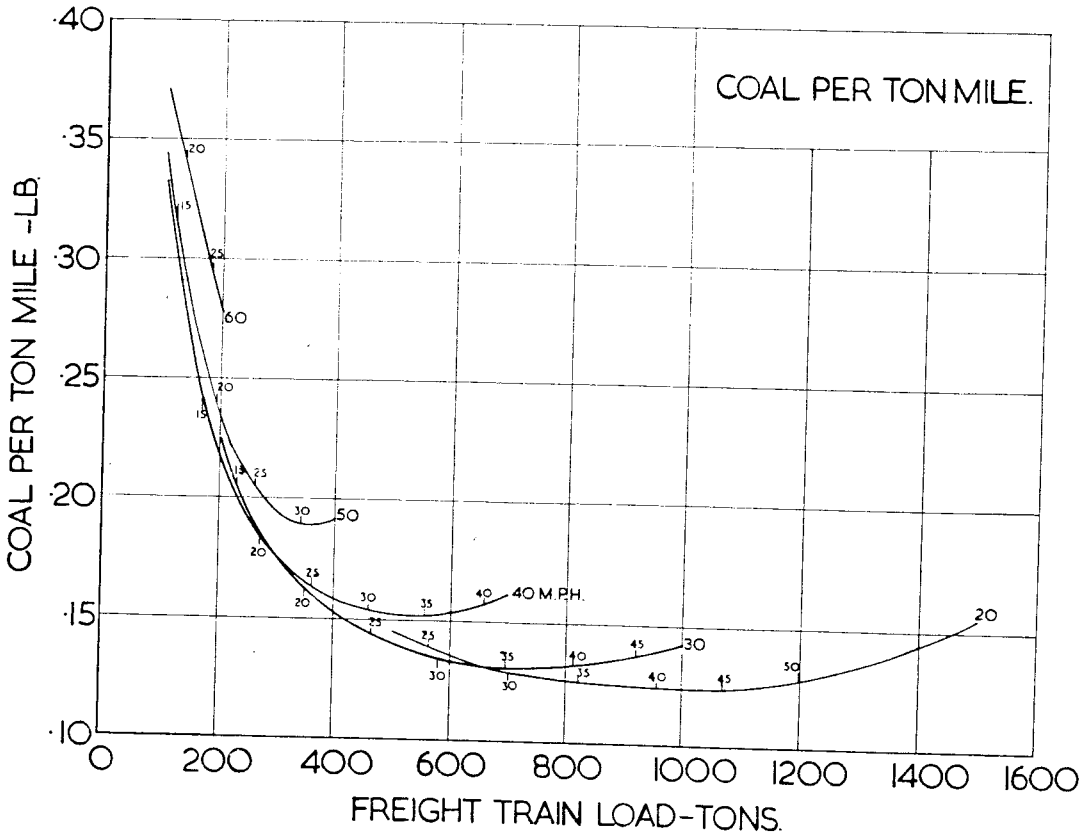
FREIGHT SERVICE — LEVEL.

EXAMPLE OF COST IN COAL OF DIFFERENT TRAIN LOADS & SPEEDS.

BLIDWORTH COAL 12600 B.Th.U/LB.

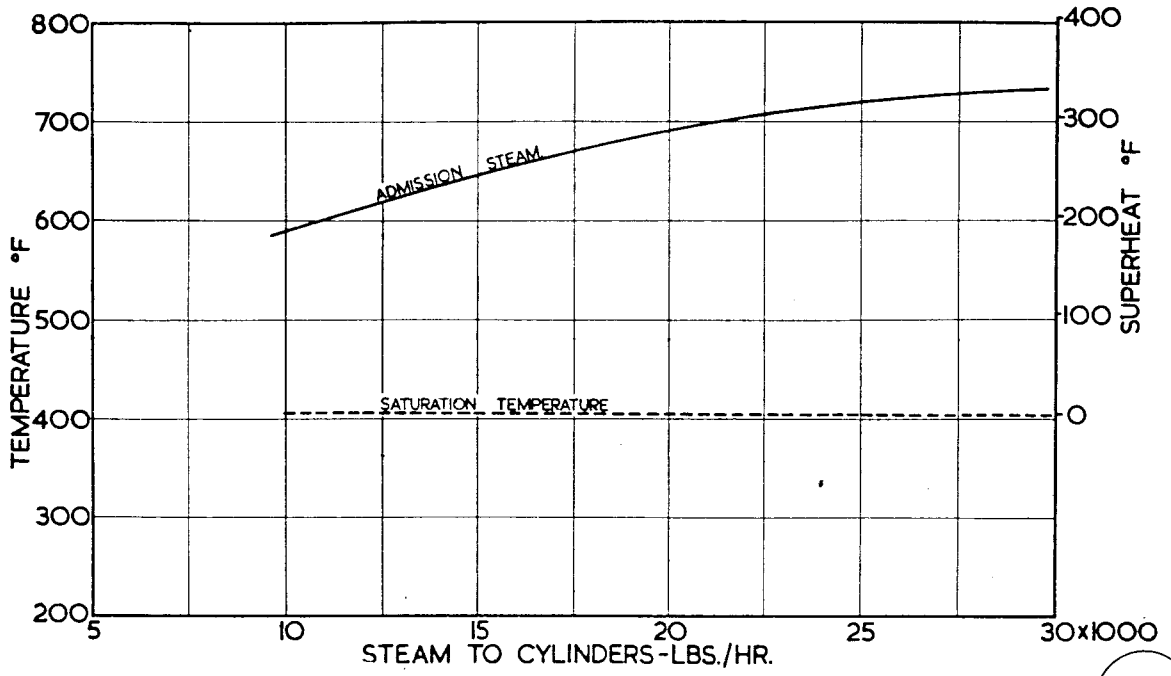
SMALL FIGURES ON CURVES INDICATE CUT-OFF MAX STEAM CHEST PRESSURE.



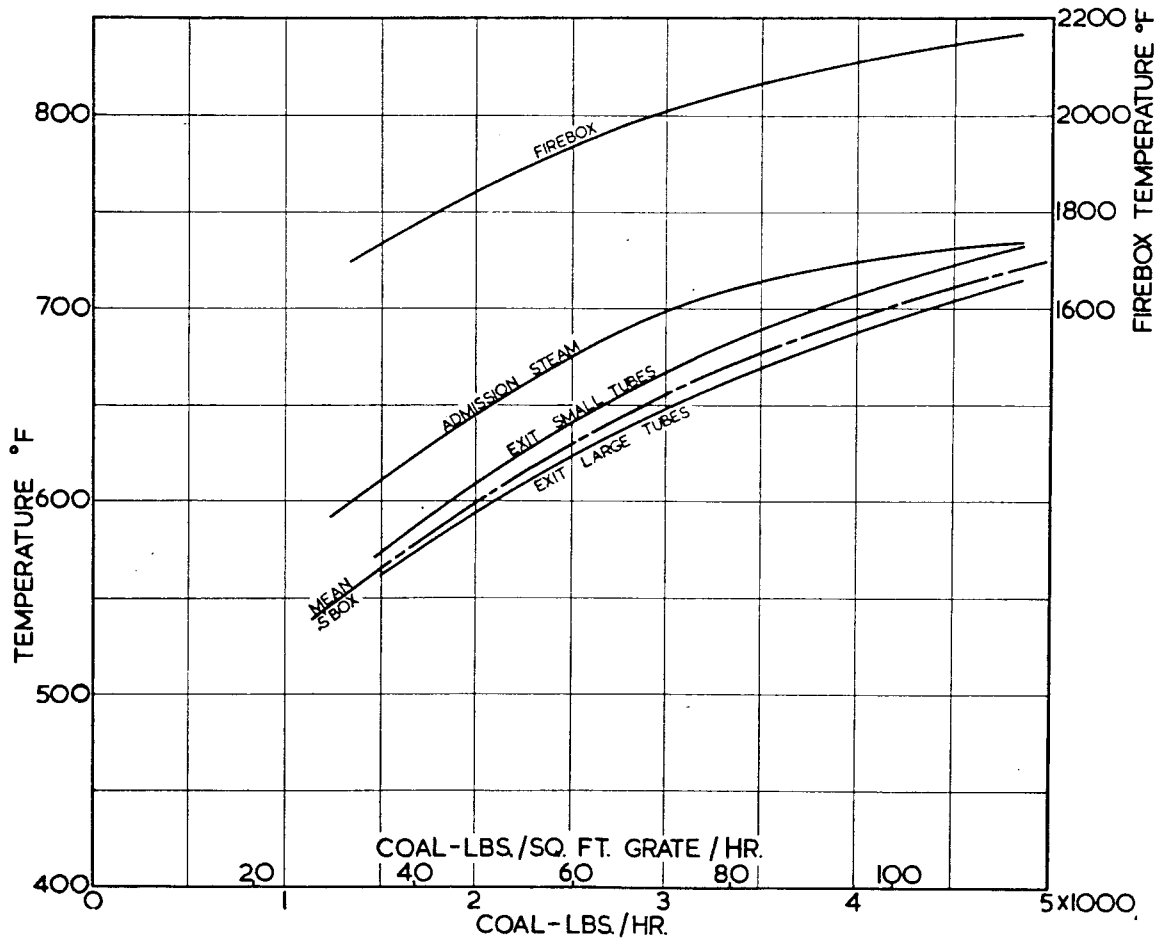


FREIGHT SERVICE - 1 IN200 RISING.

EXAMPLE OF COST IN COAL OF DIFFERENT TRAIN LOADS & SPEEDS.



30

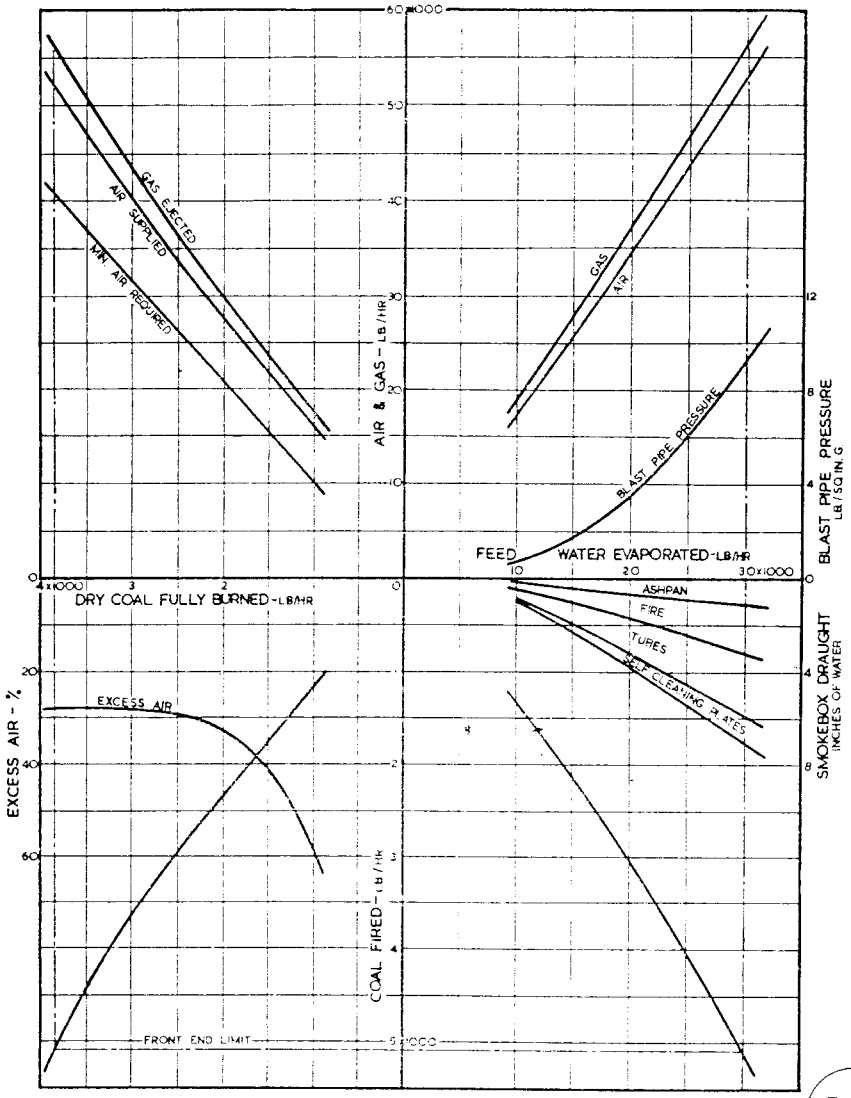


BLIDWORTH COAL - 12600 B.TH.U./LB.

EXHAUST STEAM INJECTOR

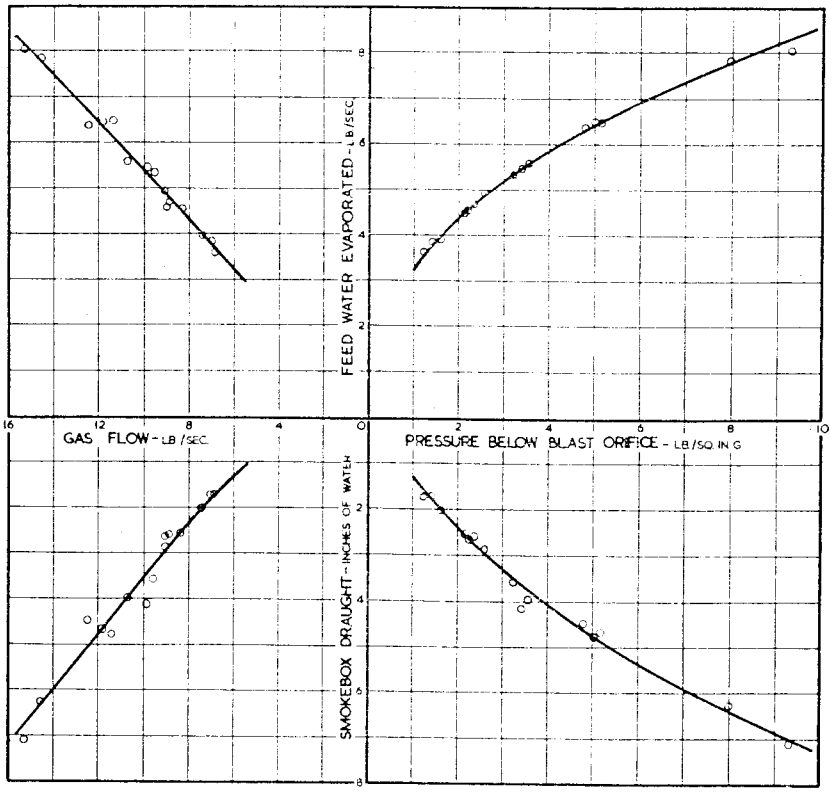
31

TEMPERATURES



STEAM-AIR-COMBUSTION

32



STEAM-GAS-DRAUGHT & BLAST PIPE PRESSURE

BLIDWORTH COAL - 12600 B.TH.U./LB.
EXHAUST STEAM INJECTOR

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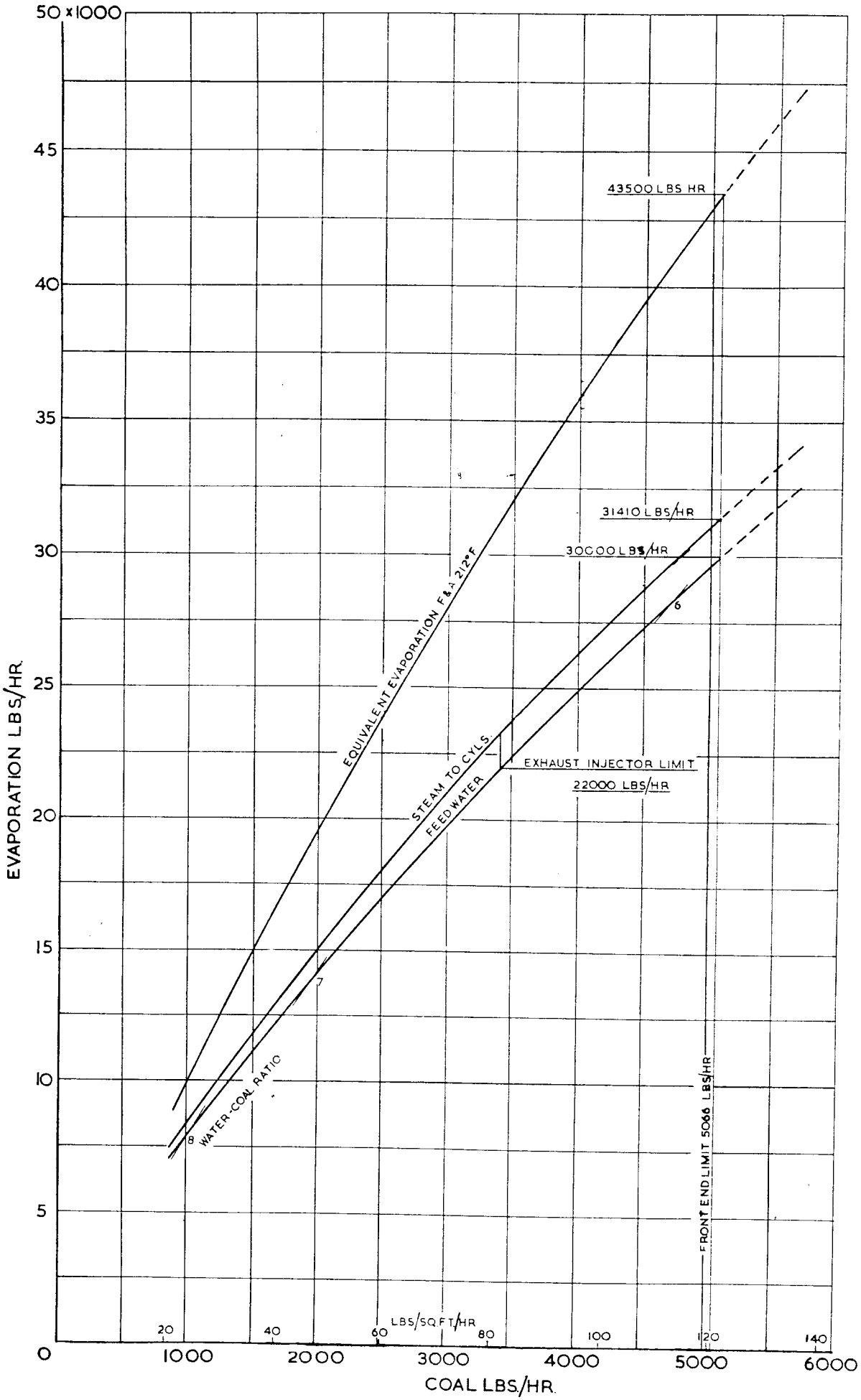
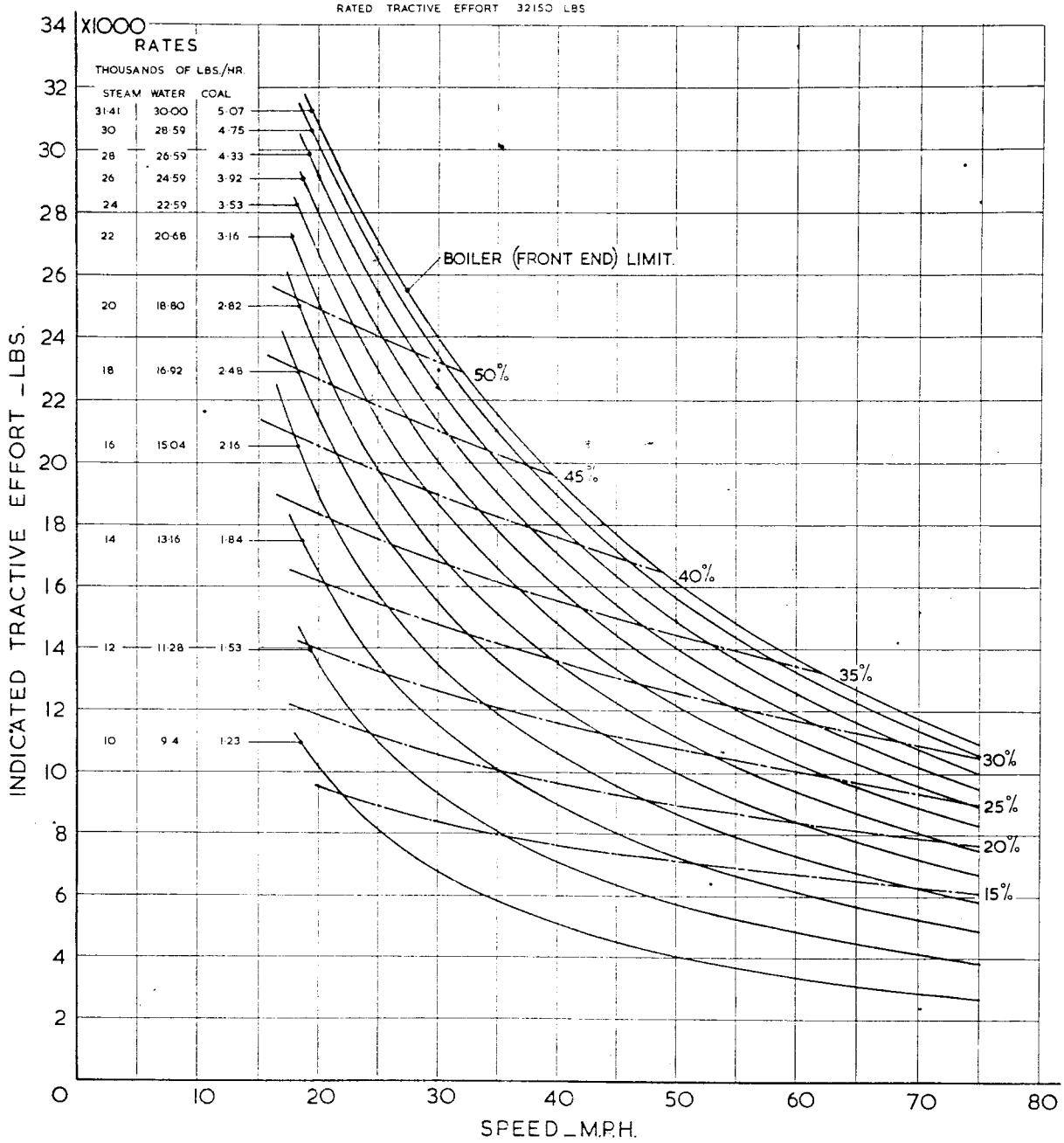

50 x 1000
45
40
35
30
25
20
15
10
5
0
EVAPORATION LBS/HR.
43500 LBS HR
31410 LBS/HR
30000 LBS/HR
EQUIVALENT EVAPORATION F & A 212°F
STEAM TO CYLS.
FEEDWATER
EXHAUST INJECTOR LIMIT
22000 LBS/HR
FRONT END LIMIT 5066 LBS/HR
8 WATER-COAL RATIO
7
6
20
40
60
80
100
120
140
LBS/SQ FT/HR
1000
2000
3000
4000
5000
6000
COAL LBS/HR.
BLIDWORTH COAL C.V. 12600 BTHU/LB.
EXHAUST STEAM INJECTOR
EVAPORATION

CUT OFFS SHOWN REFER TO MAXIMUM STEAM CHEST PRESSURE.

RATED TRACTIVE EFFORT 32150 LBS



BLIDWORTH COAL - 12600 B.Th.U./LB.

EXHAUST STEAM INJECTOR

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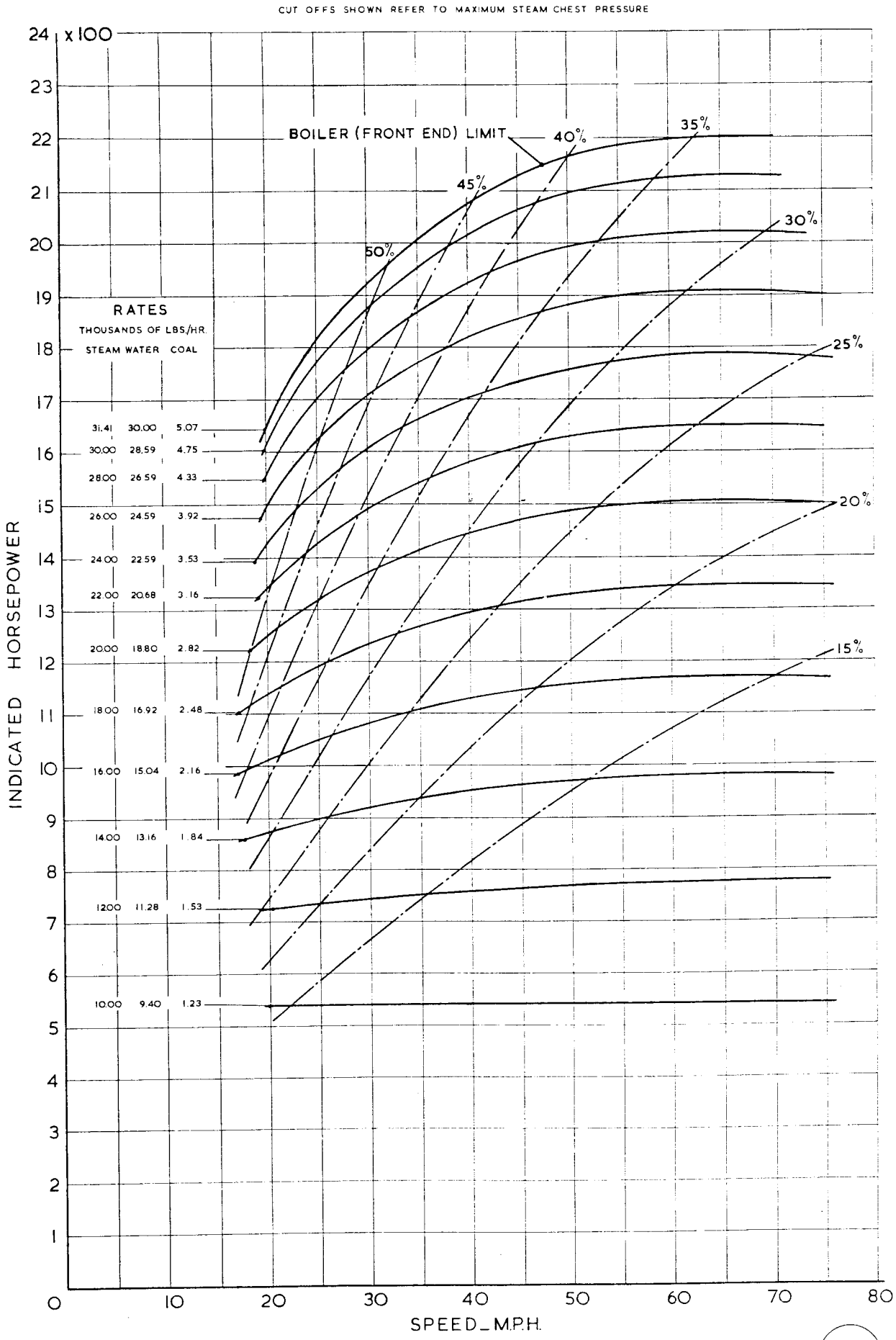
INDICATED TRACTIVE EFFORT CHARACTERISTICS



BLIDWORTH COAL_12600 B.Th.U./LB.

EXHAUST STEAM INJECTOR

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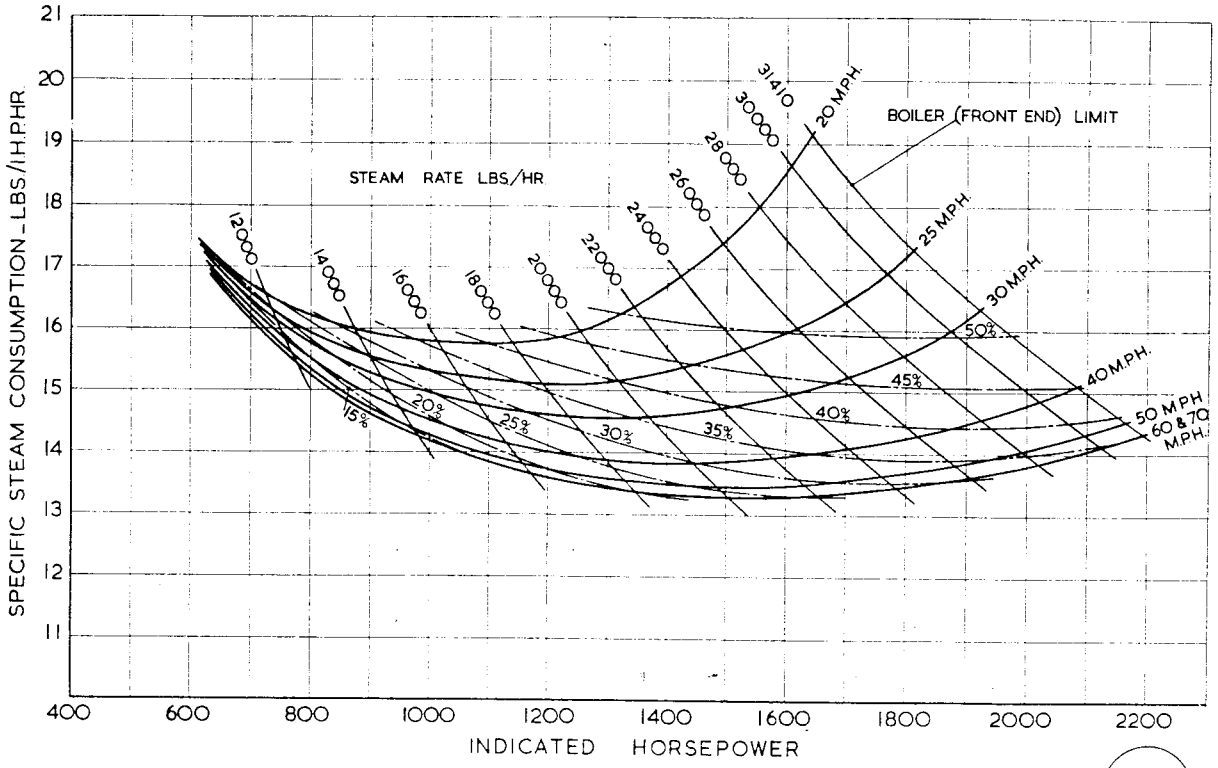
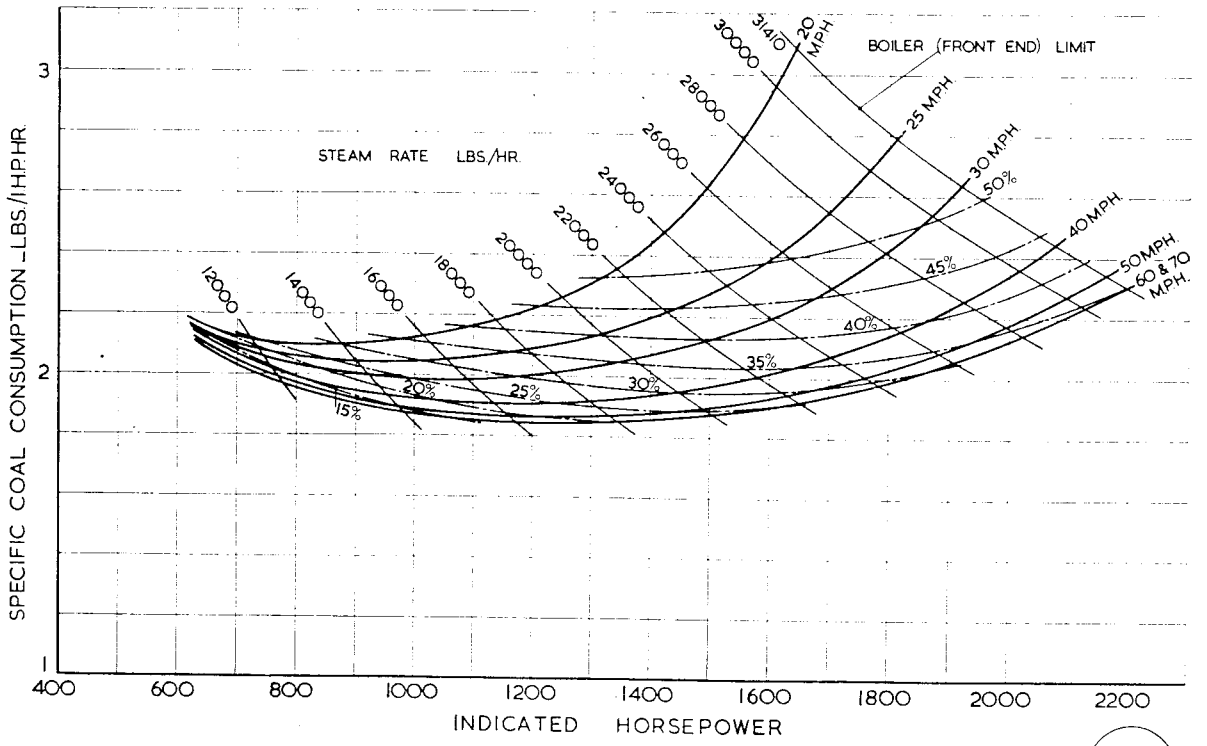
INDICATED HORSEPOWER CHARACTERISTICS



37

CUT OFFS SHOWN REFER TO MAXIMUM STEAM CHEST PRESSURE



BLIDWORTH COAL_12600 B.Th.U./LB.

EXHAUST STEAM INJECTOR

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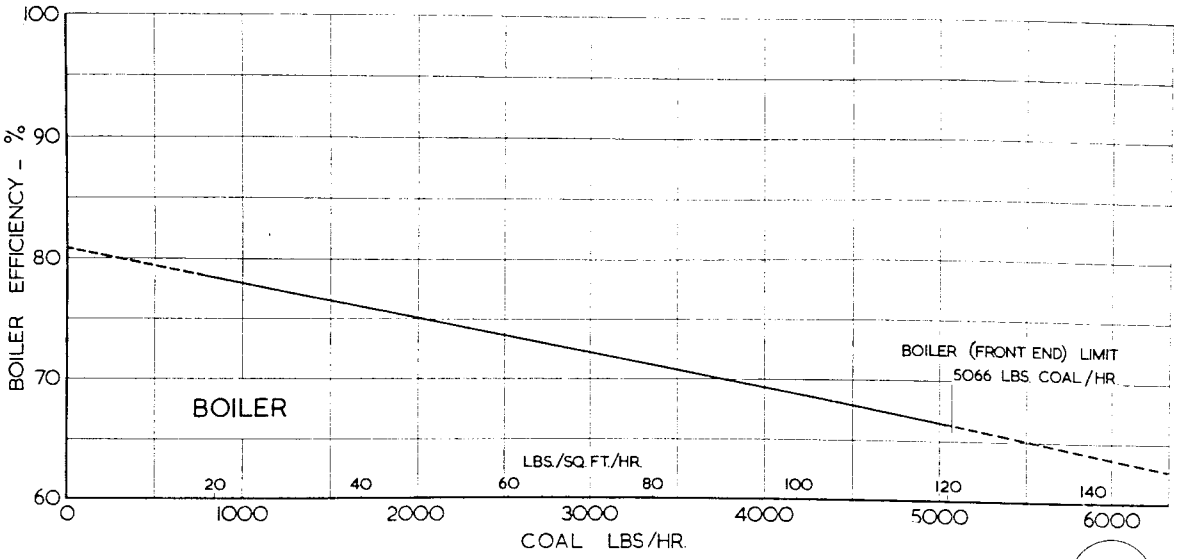
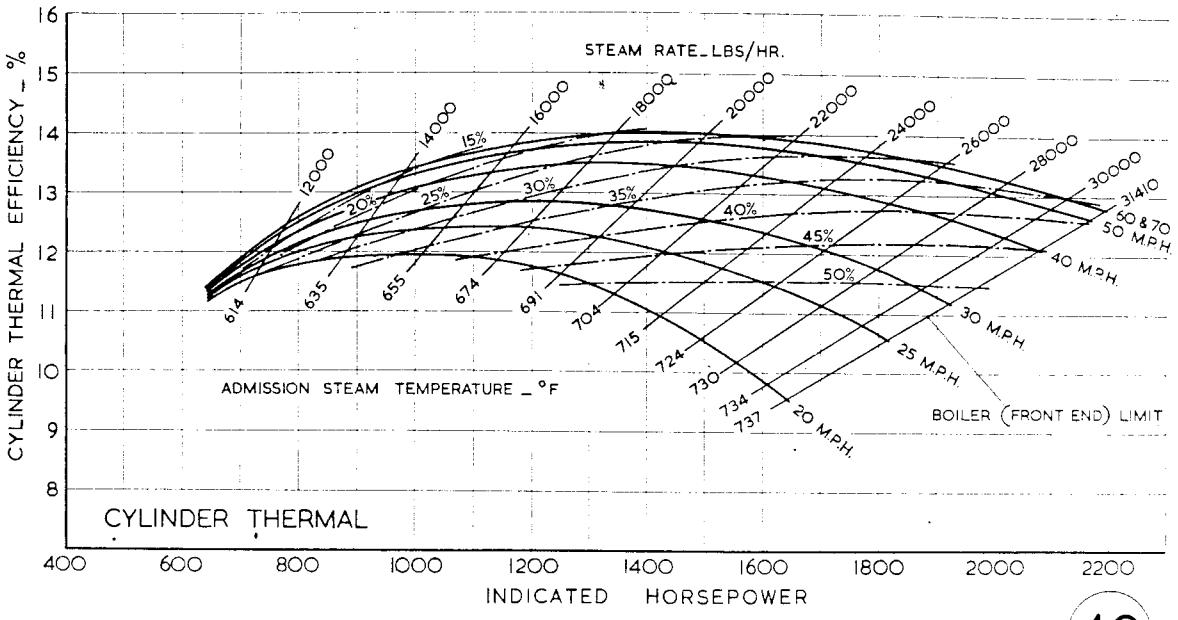
STEAM & COAL PER I.H.P. HR.

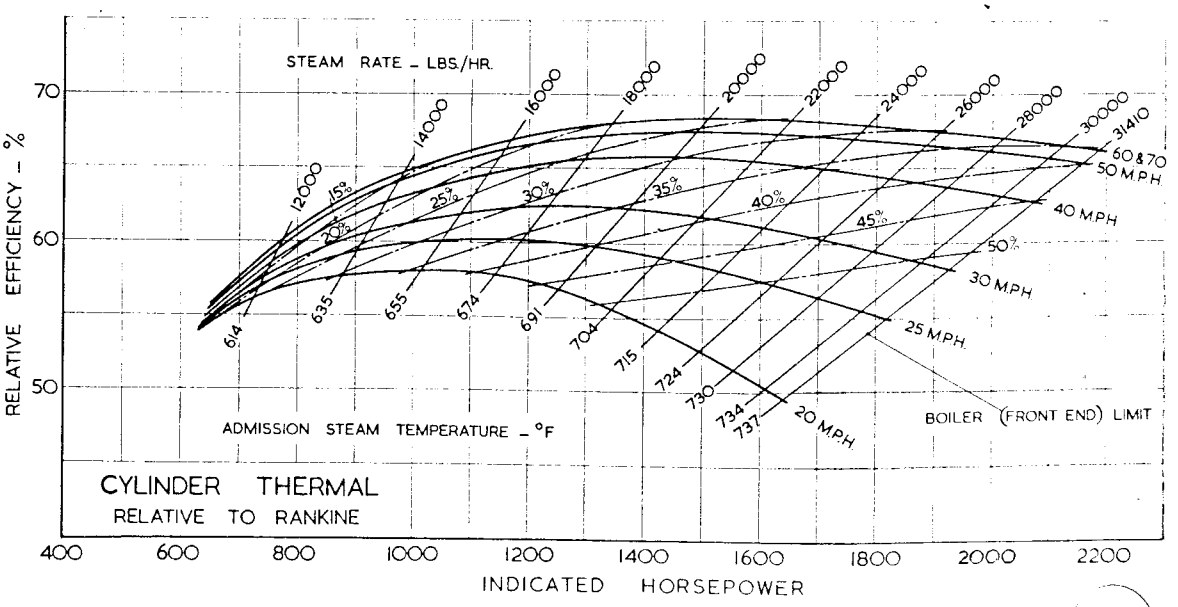


39



40

CUT OFFS SHOWN REFER TO MAXIMUM STEAM CHEST PRESSURE



BLIDWORTH COAL - 12600 B.Th.U/LB.

EXHAUST STEAM INJECTOR

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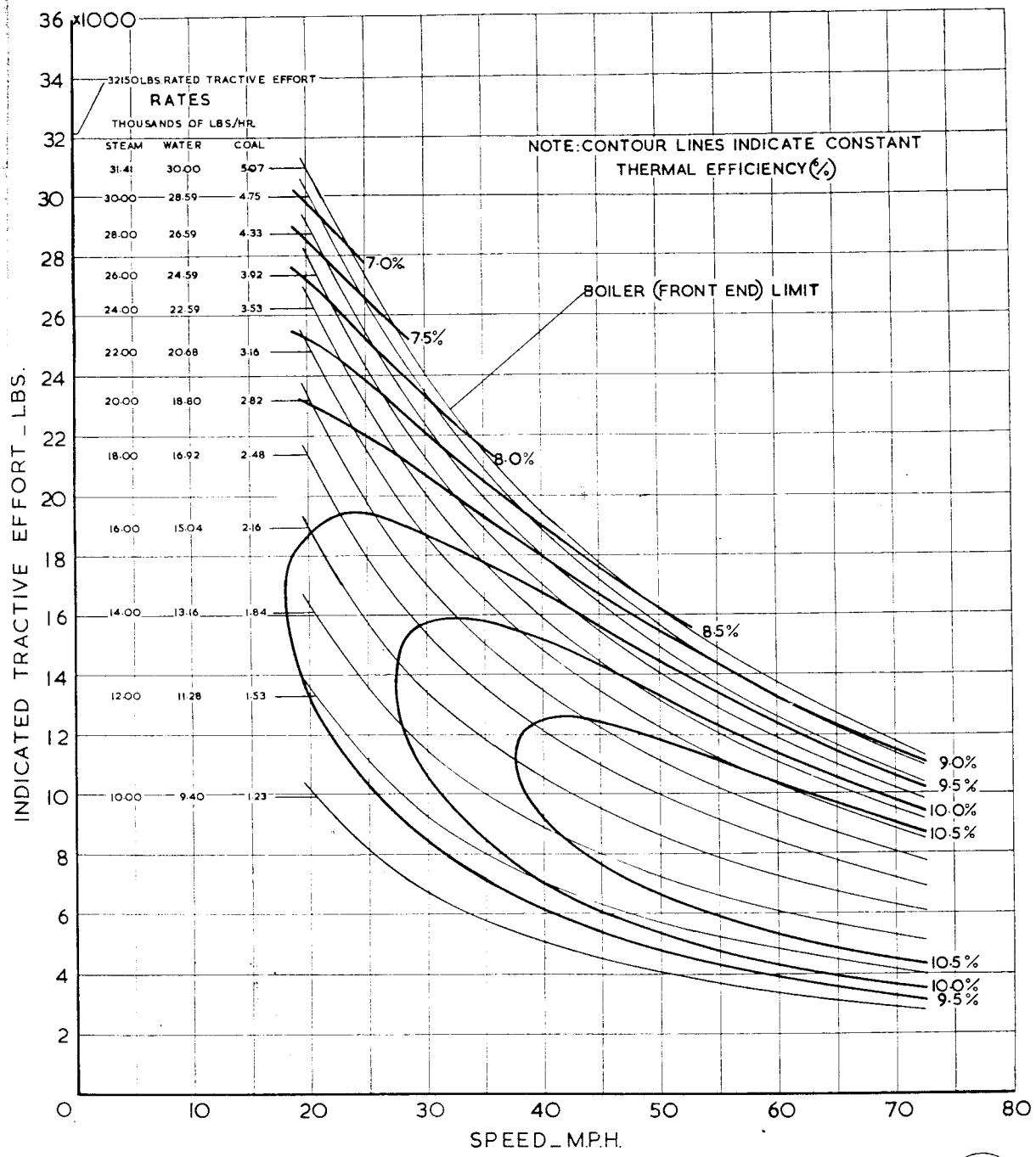
EFFICIENCIES



BLIDWORTH COAL_12600 B.Th.U./LB.

EXHAUST STEAM INJECTOR

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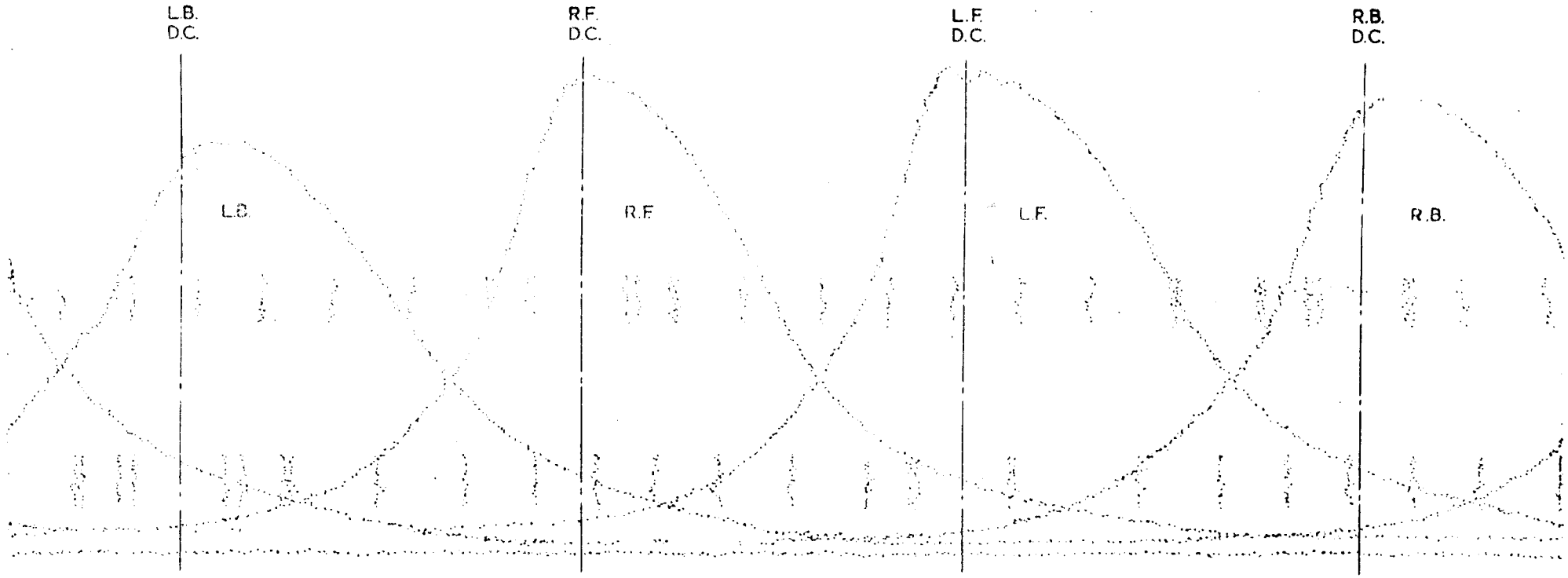
OVERALL EFFICIENCY REFERRED TO CYLINDERS

EXAMPLES OF INDICATOR DIAGRAMS

TYPICAL FARNBORO INDICATOR DIAGRAM.

STATIONARY PLANT TEST AT FULL REGULATOR

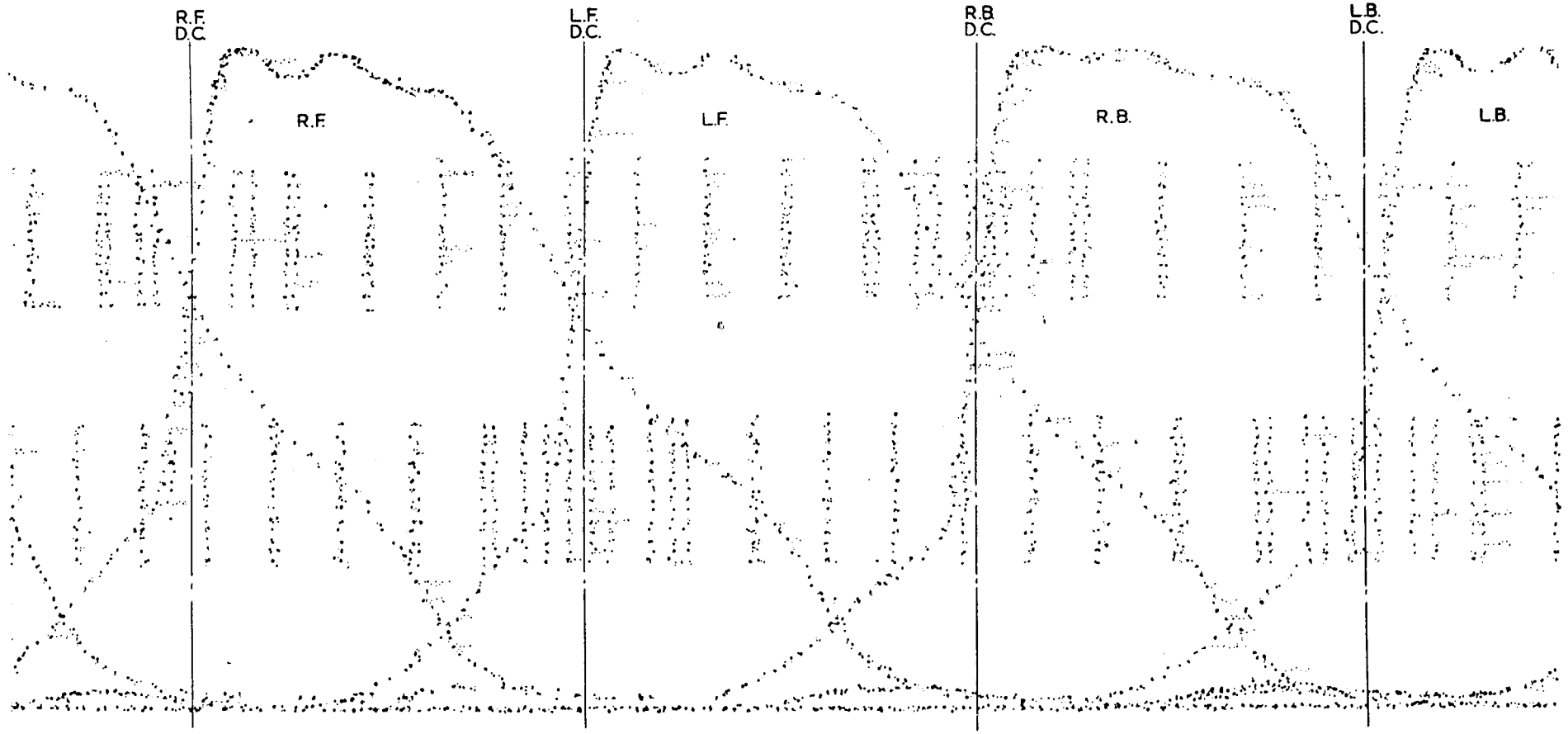
CUT OFF 15 % SPEED 69·24 M.P. H.
STEAM RATE 15210 LBS/HR. I.H.P. 1028.
INDICATOR SPRING RATE 60 LBS./IN.



TYPICAL FARNBORO INDICATOR DIAGRAM.

STATIONARY PLANT TEST AT FULL REGULATOR

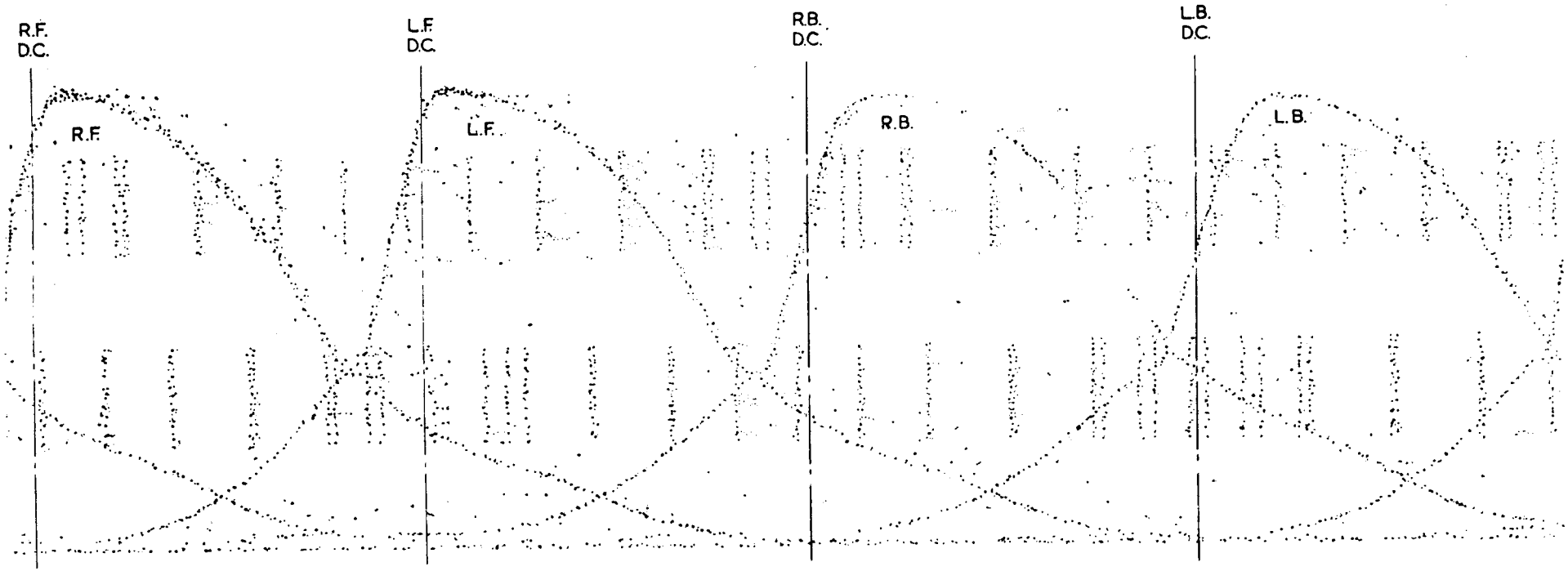
CUT OFF 40 % SPEED 20·28 M.P.H.
STEAM RATE 17640 LBS/HR. I.H.P. 1125
INDICATOR SPRING RATE 40 LBS./IN



TYPICAL FARNBORO INDICATOR DIAGRAM.

STATIONARY PLANT TEST AT FULL REGULATOR

CUT OFF 25 % SPEED 39·96 M.P.H.
STEAM RATE 18640 LBS./HR. I.H.P. 1302
INDICATOR SPRING RATE 60 LBS./IN.



TYPICAL FARNBORO INDICATOR DIAGRAM.

STATIONARY PLANT TEST AT FULL REGULATOR

CUT OFF 45 % SPEED 40·32 M.P.H.
STEAM RATE 29850 LBS./HR. I.H.P. 2006.
INDICATOR SPRING RATE 60 LBS./IN.